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## PARAMETRIC INVESTIGATION OF THE AERODYNAMIC AND AEROELASTIC CHARACTERISTICS OF ARTICULATED AND RIGID (HINGELESS) HELICOPTER ROTOR SYSTEMS

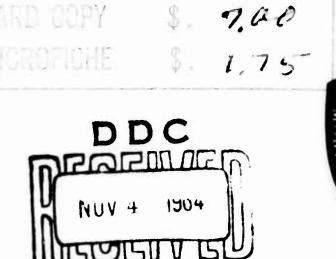
Task 1D121401A14211 (Formerly Task 9R38-11-009-11) Contract DA 44-177-TC-831

**April 1964** 

· prepared by:

SIKORSKY AIRCRAFT DIVISION

 United Aircraft Corporation Stratford, Connecticut



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This report has been reviewed by the U. S. Army Transportation Research Command and is considered to be technically sound. The report is published for the exchange of information and stimulation of ideas.

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### **FOREWORD**

This program was sponsored by the U.S. Army Transportation Research Command, Fort Eustis, Virginia, and administered by Mr. James McHugh.

The aeroelastic investigation was carried out at the Sikorsky Aircraft Division, United Aircraft Corporation, under Messrs. E. R. Wood, K. D. Hilzinger and A. C. Buffalano during the period June 1962 through October 1963. Mr. F. A. Rizzo was responsible for coordinating blade designs and processing data for over 500 flight conditions considered in the investigation. Miss Elizabeth A. O'Connor developed the extensive digital computer program required for the fully coupled blade dynamic analysis.

Guidance and helpful criticism were received from Messrs. W. Gerstenberger, E. S. Carter, K. C. Mard, and D. S. Jenney, all of Sikorsky Aircraft. Others assisting in the program from Sikorsky include Messrs. R. M. Kee and W. D. Miklus (Blade Design), J. R. Olson (Aerodynamics), J. M. Moreno and J. Laufer (Computer Technology).

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### ABSTRACT

This report presents results of an aeroelastic investigation to explore effects of parametric variations on blade stresses and performance of rigid (hingeless) and articulated helicopter rotor systems. The analysis considers the high-speed, steady-state flight condition and takes into account the fully coupled flatwise-edgewise-torsional response of the rotor blades. Substantiation for the method is based upon correlation studies with flight test data from the Lockheed CL-475 rigid rotor helicopter and Sikorsky's S-58 and S-61 articulated rotor helicopters. The study has been limited solely to steady-state flight conditions in which control, fuselage attitude and c.g. have been selected to produce no one-per-rev flapping. It should not be assumed that these flight conditions or the parameters studied are necessarily those most critical to the operation of a rigid or articulated rotor helicopter.

Calculated performance and one-half peak-to-peak flatwise stresses are shown to give good agreement with flight-measured values at higher airspeeds. In the investigation, it is found that blade twist is a significant variable for control of blade vibratory stresses and rotor performance. The sensitivity of rigid rotor flatwise and edgewise stresses to change in design of the blade root region is explored. Studies on variation of blade stiffness indicate that outboard blade stiffening is detrimental (on a moment basis) for an articulated blade, whereas inboard stiffening is detrimental for a rigid blade. For compound helicopters, selection of rotor rpm is found to require an important compromise between blade stress and power.

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### **SYMBOLS**

blade spar cross section area A lateral cyclic pitch  $A_1$ longitudinal cyclic pitch  $B_1$ number of blades b section drag coefficient  $C_{D}$ section lift coefficient  $C_{L}$ section pitching moment  $C_{\mathbf{M}}$ blade chord at radius r  $C_{(r)}$  $T/\pi R^2 \rho (\Omega R)^2$ thrust coefficient  $C_{T}$ D/C ratio of section thickness to section chord blade loading per unit length at azimuth  $\psi$  and radius r  $\frac{dL}{dr}$   $(r\psi)$ Young's modulus E aircraft gross weight gw blade spar flatwise area moment of inertia  $I_{XX}$ blade spar edgewise area moment of inertia  $I_{yy}$ ratio of spar chord to blade section chord  $L_{/C}$ Mach number M  $M_V$ half peak-to-peak bending moment rolling moment at center of rotor head in fixed co- $M_{XX}$ ordinate system M<sub>yy</sub> pitching moment at center of rotor head in fixed coordinate system

$M_{ZZ}$	yawing moment at center of rotor head in fixed co- ordinate system
R	rotor radius
r	radius to local blade station
$S_{\mathbf{X}}$	fore and aft shear at center of rotor head in fixed coordinate system
$S_y$	lateral shear at center of rotor head in fixed co- ordinate system
$S_{\mathbf{z}}$	vertical shear at center of rotor head in fixed co- ordinate system
Т	rotor thrust
t/c	ratio of spar mean wall thickness to section chord
V	aircraft forward flight speed
X	fore and aft displacement at center of rotor head in fixed coordinate system
Y	lateral displacement at center of rotor head in fixed coordinate system
$y, \frac{\partial^2 y}{\partial x^2}$	bending curvature
y <sub>v</sub>	half peak-to-peak bending curvature
Z	vertical displacement at center of rotor head in fixed coordinate system
α	section angle of attack
$oldsymbol{eta}_{T(r)}$	blade angle of twist at radius r referenced to zero at .7R
$\theta_{F}$	pitching displacement at center of rotor head in fixed coordinate system
θ <sub>.7R</sub>	collective angle as measured at .7R
$\theta_{(\psi)}$	blade impressed control angle at azimuth $\psi$

mass density of air P rotor solidity  $\frac{bc}{\pi R}$  $\sigma$ inflow angle at blade element φ φF rolling displacement at center of rotor head in fixed coordinate system blade azimuth angle, measured positive in the direction of Ψ rotation and referenced to zero at the blade full aft position yawing displacement at center of rotor head in fixed Ψ coordinate system  $\boldsymbol{\Omega}$ rotor angular velocity

### **SUMMARY**

Presented are results of an aeroelastic investigation to explore effects of flight, rotor, and blade parameters on blade stresses and performance of articulated and rigid (hingeless) rotor systems in high-speed flight. Variations in blade planform and twist, rotor lift and propulsive force, blade stiffness and mass distribution are investigated for helicopters and compound helicopters at several gross weights for speeds from 150 to 300 knots. The analysis takes into account the fully coupled flatwise-edgewise-torsional response of the rotor blades. Substantiation for the method is based upon correlation studies with flight test data from the Lockheed CL-475 rigid rotor helicopter and Sikorsky's S-58 and S-61 articulated helicopters.

In all, 504 data points are considered in the investigation, which treats the steady-state flight condition. A few of the noteworthy results explained are: (1) the trends of blade twist as a significant variable for control of blade stresses and rotor performance; (2) the sensitivity of rigid rotor flatwise and edgewise stresses to change in design of the blade root region; and (3) the effects of blade weights as a means to reduce blade vibratory stresses for both rotor systems.

Extension of this work to critical consideration of transient and other flight conditions is discussed under "Recommendations". It must be emphasized that the study reported herein has been limited solely to steady-state conditions in which control, fuse-lage attitude and c. g. have been selected to produce no one-per-rev flapping. Because of the obviously critical effect of flapping on hingeless rotor root bending moments and because transient manuever, c. g. variations and off-design trim attitudes inevetably must produce flapping, this area is clearly one for further investigation.

### **CONCLUSIONS**

Results are presented from an analytical program to explore effects of parametric variations on blade stresses and performance of rigid\* and articulated rotor systems. The analysis considers the high-speed, steady-state flight condition and takes into account the fully coupled flatwise-edgewise-torsional response of the rotor blades. For the studies, constant inflow is assumed.

The rigid or hingeless rotor designs were configured to criteria established by the Lockheed-California Company (see Section 4). For uniform planform blades investigated, these criteria resulted in "rigid" designs which were equivalent to articulated rotors with from 15% to 30% flapping offset, where equivalence was based upon the frequency of the first flapping mode.

### A. CORRELATION

Calculated performance and one-half peak-to-peak flatwise stresses are shown to give good agreement with flight measured values for both rigid and articulated rotor helicopters at higher airspeeds. As reported in References (1) and (2), results indicate that one-half peak-to-peak blade stress may be accurately calculated at high airspeeds without variable induced velocity. For low airspeeds, however (below 100 knots), variable inflow is required to calculate one-half peak-to-peak bending stresses. Also, variable inflow effects are required to accurately predict higher frequency airloads and blade stresses at all airspeeds. For compound helicopters, where the rotor angle-of-attack is near zero, the validity of constant inflow for blade stress calculations is open to question. Final evaluation will depend upon test data for this type of aircraft.

### B. PARAMETRIC TRENDS

Conclusions which may be drawn from results of the parametric investigation include:

<sup>\*</sup> As used within this report, the term "rigid" refers to a rotor system without flapping or lag hinges. In the strictest sense, this term is misleading since the blade root region for such a rotor system has flexibility contributed by both bearings and blade spar.

- Blade twist was found to be a significant (1) variable for control of blade stresses and rotor performance. Increased negative twist acts to unload the retreating and load the advancing blade. Due to the helicopter's pitch-trim requirements, the advancing blade must carry the increased load on the inboard panels rather than the more efficient outboard The resulting one-per-rev load dissymmetry is the aerodynamic cause of increased blade vibratory stress. This means, on a vibratory stress basis, that the advancing blade and not the retreating blade becomes critical for large negative twist. Results of calculations for planform-twist variation indicate a rapid rise in vibratory bending moments with increase in blade twist for rigid and articulated rotor systems. Small values of negative twist resulted in minimum blade stress, while the optimum power-twist tradeoff required larger values of negative twist. Also, the power-twist gradient was noted to be much lower than the stress-twist gradient. The value of blade twist for minimum vibratory stress was noted to be relatively independent of the aircraft's mission, whereas power minimums For the aircraft showed noticeable variation. considered, blade twist to minimize stress was found to be in the region of +2 degrees to -2 Optimum power for helicopters was degrees. found to be in the region of -8 degree twist; for the jet compounds, in the region of -4 degrees: and for the winged compounds, in the region of 0 degree. For winged compounds, variation in power with change in blade twist was found to be small.
- (2) Studies on variation of blade stiffness indicated that outboard blade stiffening was detrimental (on a moment basis) for an articulated blade, whereas inboard stiffening was detrimental for a rigid blade. Blade stiffening effects may or may not reduce blade stress depending upon the

- tradeoff between bending moment and section modulus at the critical blade station.
- (3) Addition of blade weights can be beneficial. Reduction in vibratory bending moments was observed for both rigid and articulated blades by introducing a concentrated weight at the blade tip. For the 33, 000-pound helicopter considered, greatest reduction was achieved for both systems with the first 10 pounds added; there was less reduction thereafter. Tapered blade mass distribution did not appear to offer any significant advantage.
- several important compromises. Reduced rotor speed is required to alleviate effects of compressibility and to lower overall power requirements. However, a more demanding condition for rotor speed may be blade life and reliability. Here, accurate control of rotor rpm is important due to rapid changes in stress and power with rpm fluctuations. This means that gust and maneuver conditions may govern compound helicopter design.
- For compound helicopters, autorotation of the rotor was found to be a poor flight condition based on blade stress and total power required. Setting the rotor near zero angle-of-attack with the rotor providing only lift, and using external propulsive force to overcome rotor drag, resulted in a satisfactory flight condition. Rotor angle-of-attack with respect to the air stream may be controlled by cyclic pitch and power input to the shaft.
- (6) Results of rotor hub impedance studies indicated that blade-fuselage coupling may be important in predicting higher harmonic blade response and associated fuselage response.

(7) Inclusion of torsion in the blade analysis did not essentially alter the character of the azimuth-wise distribution of flatwise bending moments, but did yield higher vibratory values than were predicted when torsion was not included. With torsion added, control loads could be calculated. Here, with increase in airspeed a buildup in magnitude of calculated control loads was observed. Also noted was an increase in their higher harmonic content.

### C. DESIGN CONSIDERATIONS

Available to the blade designer is both a selection of material and a range of section moduli to meet stress requirements. With this freedom it is possible to bring about significant changes in resulting stress patterns. For this reason, results in this report are compared on a bending moment rather than stress basis. This, of course, makes comparison susceptible to size effect, but it properly reflects blade mass and stiffness distribution, yet avoids the open question of the many possible section moduli which can be selected to carry imposed bending moments.

Rigid rotor flatwise and edgewise vibratory moments were observed to be sensitive to design of the blade root region. For this rotor system, properly designed flexibility gave a root restraint which was between a theoretical rigid and hinged condition. For chordwise design of rigid blades, tuning was especially important due to high amplication of edgewise moments as the inplane frequency approached one-per-rev. Lockheed criteria (See Section 4) for high aspect ratio blades (A. R. > 18) specifies flexible design of the root to place the first edgewise mode at about 0.65 $\Omega$ . Note that this rotor is brought up to operating speed through the one-per-rev range. For these blades, design consideration should be given to adequate control of edgewise stress during run-up.

For the articulated blade, maximum vibratory moments generally occurred at the two-thirds blade radius, while location of maximum centrifugal stress was at the blade root. The rigid blade did not have this separation of design points. Here, both maximum steady and maximum vibratory values occurred at the blade root. To control combined stresses the rigid rotor designer must weigh area requirements (to carry steady centrifugal loads) and stiffness requirements (for blade dynamic response) in the blade root region.

Blade stiffness changes were found to be significant for both rotor systems in the region of maximum vibratory moment. Adding material to the blade in this region may or may not reduce stress depending upon the tradeoff between bending moment and section modulus. For section moduli considered in this study, an increase in vibratory stresses was generally noted with increased stiffness.

### **RECOMMENDATIONS**

While this study was principally concerned with blade parametric variations in high-speed, steady-state flight, it should not be assumed that these flight conditions and parameters are necessarily those most critical to the operation of an articulated or rigid rotor design. Serious consideration should also be given to other areas which are outside the scope of this study. These include: (1) effects of gusts and maneuver loads on blade stresses for both rotor systems; (2) stability and control of each rotor system in high-speed flight and associated blade stresses; and (3) for compound helicopters, effects of rotor angle-of-attack on stability and stresses for both rotor systems, and the significance of variable inflow when the rotor is near zero angle-of-attack.

Although not covered within the scope of this report, a preliminary study was made of effects of fuselage c. g. shifts on blade stresses. Early results indicated that rigid blade stresses were more sensitive to fore and aft shifts of the fuselage c. g. than corresponding articulated blade stresses. Fore and aft c. g. shifts appeared to induce a one-per-rev load dissymmetry, which the rigid rotor responded to by bending, while the articulated rotor responded in flapping. Effects of longitudinal and lateral c. g. shifts on associated blade stresses should be explored in more detail for each rotor system.

At particular airspeeds, it appeared possible to obtain the effect of planform taper on aerodynamic loads by proper choice of twist on a 1:1 taper blade. This effect should be explored in more detail due to the relative simplicity of changing twist when compared to changing blade planform.

### 1. INTRODUCTION

Design of helicopters and compound air vehicles for higher airspeeds requires greater knowledge of rotary-wing dynamics and performance than is presently available from published analyses and investigations. For fuller understanding of advanced flight regimes, an analytical program was required, which would explore effects of forward speed, blade planform, blade twist, rotor lift and propulsive force, blade stiffness and mass distribution, rotor tip speed and altitude on the blade motions, blade stresses, and performance of articulated and rigid rotor systems.

To provide this information, Sikorsky Aircraft last year undertook a study for the U.S. Army Transportation Research Command. This report gives results of that study. The work was carried out by a joint effort of the company's Aerodynamic, Blade Design, and Dynamics Sections. Three well developed analytical programs were used in the study: (1) an Advanced Performance Analysis, which was used to determine the basic rotor parameters to be studied: (2) a Horvay-type Blade Design Analysis, which has been responsible for Sikorsky's present-day successful blade designs; and (3) a Coupled Blade Flatwise-Edgewise-Torsional Aeroelastic Analysis, which yields the full spectrum of blade dynamic information. The aeroelastic analysis is general and well suited for studies of a wide range of helicopters and VTOL-type aircraft with rotor blade and propellers of all types. As will be shown in the report, good correlation has been achieved with the method for both rigid and articulated rotor systems.

The report which follows treats each phase of the investigation separately. First, the scope of the program is described, and variations in parameters are outlined by means of tables and flow charts. Next, aerodynamic criteria are established from which basic rotor parameters are determined. Blade design criteria are discussed. Based on this, structural characteristics are developed for the sixteen basic rotor systems considered in the program. Also set forth are criteria followed in extrapolating blades of one planform to those of another.

Development of the aeroelastic analysis is presented with reference to two earlier papers which describe the method in greater detail. Included in this section is a discussion of steps taken to check out the digital computer program. Following this, correlation of analysis with flight test data is presented for the Lockheed CL-475 rigid rotor helicopter and Sikorsky's S-58 and S-61 articulated helicopters.

Significant trends resulting from calculations for 504 separate flight conditions comprise the major part and remainder of the report. Wherever possible, efforts have been directed toward explaining trends, as well as presenting them. Included are discussions on such topics as increase in vibratory stress with negative twist, and rotor system power-stress tradeoff at high speeds.

### 2. SCOPE OF PROGRAM

Included in the overall study are eight basic aircraft. four in the 12,000-pound class and four in the 33,000-pound class. The design configurations are two 150-knot helicopters, two 180-knot helicopters, two 200-knot wingless compounds, and two 250-knot winged compounds. Four planform variations are considered in each case, and blades are taken as both rigid and articulated. Table 2.0 presents a summary of aircraft considered and includes a listing of basic aircraft parameters. Basic parameters were the same for both articulated and rigid rotor (designated -R) designs. Profile and plan view drawings of the eight designs are presented in Figures 2.1 through 2.8. Blade planform variations are given in Figure 2.9. Table 2.1 gives the range of flight conditions treated in the investigation.

Shown in Tables 2. 2 through 2.6 are the schedules of calculations performed under the program. Tables 2.7 through 2.9 are flow charts which illustrate the order of calculations. In all, 504 data points were calculated for the patametric investigation.

Given in Appendix A, Figures A-1 through A-8, are fuselage lift and drag curves versus airspeed for the aircraft considered. Helicopter fuselage lift and drag data are presented in Figures A-1 through A-4. Variation of these curves from simple V<sup>2</sup> curves is due to changing body attitude with change in airspeed. Fuselage lift and drag data were similar for both rigid and articulated rotor helicopters performing the same mission.

Fuselage drag data for compound helicopter designs are presented in Figures A-5 through A-8. Here, a simple  $V^2$  relation was used since aircraft attitude would be held substantially constant at higher airspeeds. Details of compound trim conditions are discussed in Section 3.

Criteria by which detailed design of the respective rotor systems was determined are discussed in Sections 3 and 4, which follow. Resulting blade stiffness and mass properties are tabulated in Appendix B, Tables B-1 through B-64. These provided the basic input to the aero-elastic analysis, which is described in References 1 and 2 in detail, and in brief in Section 5 of this report.

Results of the aeroelastic investigation are summarized within this report where plots of pertinent parameters have been made and significant trends noted. Calculations were done on an IBM 7090 digital computer at United Aircraft Corporation's Research Division in East Hartford, Conn. Each of the 504 data points required 5 minutes of computer time. For each data point, the following information was

obtained on IBM printout sheets in addition to input data.

- 1. Cyclic pitch at 36, 10-degree azimuth intervals.
- 2. Thrust moment about the flapping hinge at 36, 10-degree azimuth intervals.
- 3. Blade element thrust 756 values representing the lift on each of 21 blade elements at 36, 10-degree azimuth intervals.
- 4. Blade element drags 756 values representing the drag on each of 21 blade elements at 36, 10-degree azimuth intervals.
- 5. Blade element pitching moments 756 values representing the pitching moment on each of 21 blade elements at 36, 10-degree azimuth intervals.
- 6. Blade element thrust steady plus 7 harmonics in complex form for 21 blade stations.
- 7. Blade element drag steady plus 7 harmonics in complex form for 21 blade stations.
- 8. Blade element pitching moments steady plus 7 harmonics in complex form for 21 blade stations.
- 9. Blade dynamic response:
  - a. For each of 24 blade stations, 8 responses in complex form, the steady plus seven harmonics of blade response: flat-wise amplitudes, moments, shears, and slopes; edgewise amplitudes, moments, shears, and slopes; torques and torsional deflections.
  - b. Total response: For each of 21 blade stations at each of 36, 10-degree azimuth intervals: flatwise amplitude, moment, shear, slope, and stress; edgewise amplitude, moment, shear, slope, and stress; torque, torsional deflection, and torsional stress; maximum peak-to-peak flatwise stress, edgewise stress, and torsional stress and radial station at which each occurs.

TABLE 2.0

DESCRIPTION OF AIRCRAFT

AIRCRAFT DESIGNATION	H1 H1-R	H2 H2-R	H3 H3-R	H4 H4-R	C1 C1-R	C2 C2-R	C3 C3-R	C4 C4-R
GROSS WT. (LBS.)	12000	33000	8700	30000	12000	27000	14000	30000
MISSION V CRUISE (KTS.)	150	150	180	180	200	200	250	250
BLADE RADIUS (FT.)	31	36	28	36	28	36	28	35
ROTOR SPEED (RPM)	203	185	230	179	222	186	168	135
TIP SPEED (FPS)	660	696	675	675	650	700	493	493
NO. OF BLADES	<b>S</b> 1	6	5	<b>∞</b>	6	6	5	4
AIRFOIL SECTION	0012	0012	0012	0012	0012	0012	0012	0012
DESIGN TWIST FOR 1:1 TAPER BLADE (DEG.)	<b>∞</b>	-6	4.	<b>&amp;</b>	4.	<b>&amp;</b>	-2	-2
CHORD (IN.)	18. 25	23.65	18. 25	19. 80	18. 25	23.65	18. 25	36.00
OFFSET (IN.)	12.625	24	12.625	24	12.625	24	12.625	30
PERCENT GROSS WEIGHT CARRIED BY ROTOR	100	100	100	100	96	100	15	15
SOLIDITY	.07804	.1046	.086	.1165	.1045	.1045	.086	.110
CT/G	050	.068	.039	.059	.045	.054	.017	.018

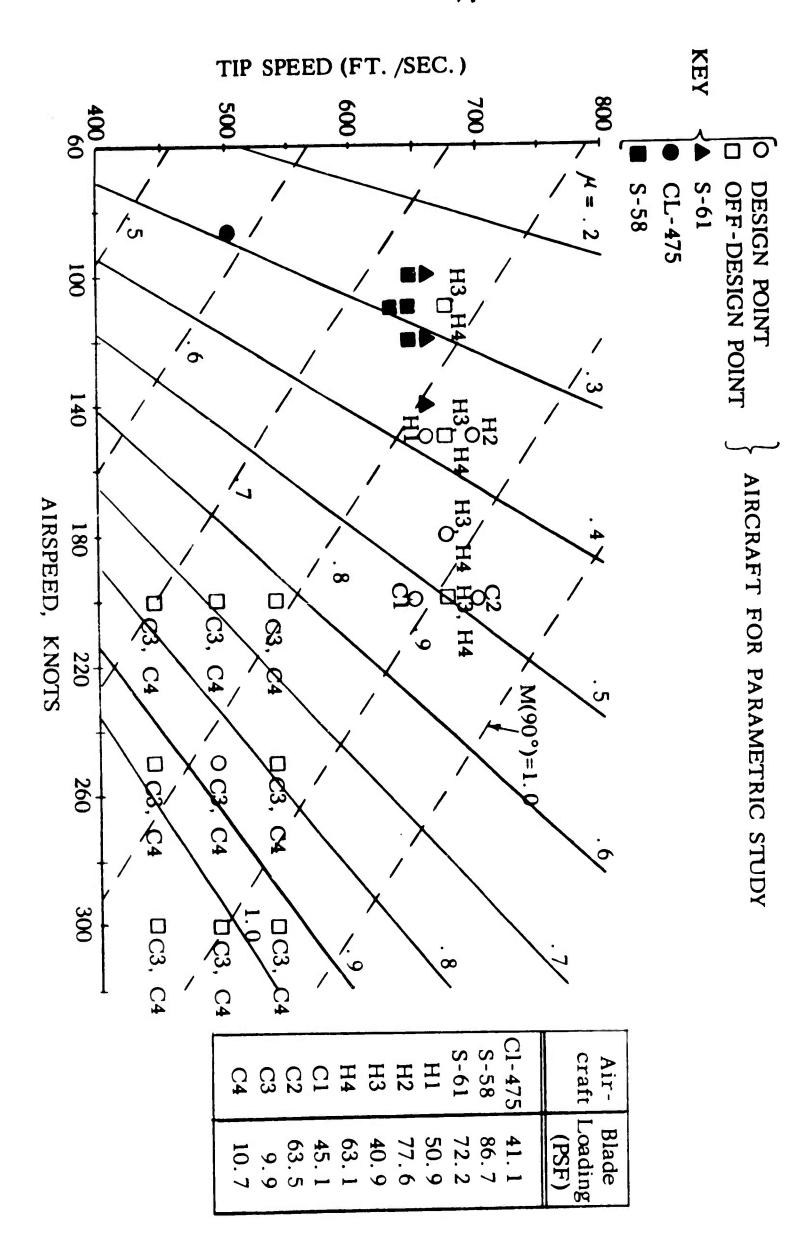


TABLE 2. 1
RANGE OF FLIGHT CONDITIONS

#### PERFORMANCE SCHEDULE

#### HELICOPTER

- 1. Gross Weight: 12000, 33000 lb. at 150 kt. 8700, 30000 lb. at 180 kt.
- 2. Altitude: Sea Level
- 3. Blade Twist: 0, -4, -8, 16° \*(128)
- 4. Blade Planform: 1:1, 3:1, 1:2, nonlinear
- 5. Retention: Articulated, Rigid

#### COMPOUND HELICOPTER

- 1. Gross Weight: 12000, 27,000 lb. at 200 kt. 14000, 30000 lb. at 250 kt.
- 2. Altitude: Sea Level
- 3. Blade Twist: +4, 0, -4,  $-8^{\circ}$  at 200 kt. +2, 0, -2,  $-4^{\circ}$  at 250 kt. (128)
- 4. Blade Planform: 1:1, 3:1, 1:2, nonlinear
- 5. Retention: Articulated, Rigid

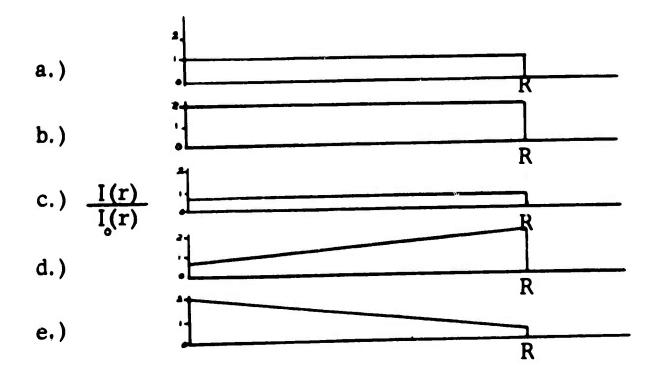
The following additional variations were investigated for the aircraft indicated, using a 1:1 blade planform and design twist. Each variation is made assuming all other parameters constant at the assumed value of the above study.

- a.) Altitude: 5,000, 10,000, 15,000, 20,000 ft. (56) (All aircraft)
- b.) Parasite Drag: 3 variations (44) (180-knot helicopters at 4 different speeds)
- c.) Rotor RPM: 3 variations (44) (250-knot compounds at 4 different speeds)
- \* Number of data points.

# TABLE 2.3 STIFFNESS SCHEDULE

### HELICOPTER

- 1. Gross Weight: 33000 lb.
- 2. Air Speed: 110, 150, 180 kts.
- 3. Retention: Rigid (all speeds) (15)
  - Fully Articulated (all speeds) (15)
  - Teetering Rotor Head (150 kts. only) (15)
- 4. Blade Planform: 1:1
- 5. Blade Twist: Design Value
- 6. Blade Parameters: All parameters standard configuration except as noted in 7.
- 7. Stiffness Variations:  $I/I_0$  vs. R



#### MASS DISTRIBUTION SCHEDULE

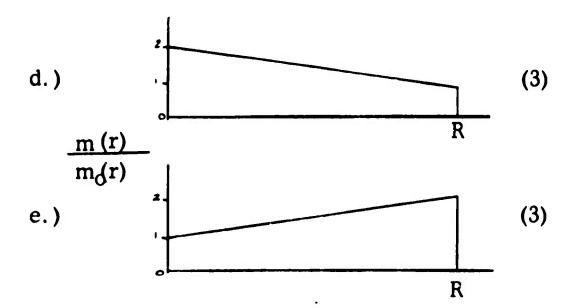
#### HELICOPTER

- 1. Gross Weight: 33000 lb.
- 2. Air Speed: 150 kt.
- 3. Retention: a.) Rigid
  - b.) Articulated
  - c.) Teetering Rotor
- 4. Blade Parameters: All parameters standard

configuration except as

noted in 5.

- 5. Mass Variation:
  - a.) Concentrated mass at 5 radial locations (15)
  - b.) Two concentrated masses (5 variations in location)
  - c.) Single concentrated mass at optimum location (5 variations in mass) (15)



### ROTOR HEAD IMPEDANCE SCHEDULE

#### HELICOPTER

- 1. Gross Weight: 33,000 lb.
- 2. Air Speed: 150 kt.
- 3. Planform: 1:1 Design Blade (7)
- 4. Twist: Design
- 5. Seven variations in rotor head impedance

# BOUNDARY CONDITIONS SCHEDULE

#### HELICOPTER

- 1. Gross Weight: 33000 lb.
- 2. Air Speed: 150 kt.
- 3. Planform: 1:1 Design Blade
- 4. Twist: Design
- 5. Boundary Conditions:
  - a.) Articulated flatwise, cantilevered edgewise
  - b.) Articulated flatwise, articulated edgewise (3)
  - c.) Cantilevered flatwise, articulated edgewise

#### ROOT FLEXIBILITY SCHEDULE

#### HELICOPTER

- 1. Gross Weight: 33,000 lb.
- 2. Air Speed: 150 kt.
- 3. Planform: 1:1 Design Blade
- 4. Twist: Design
- 5. Boundary Conditions:

articulated flatwise - articulated edgewise except as noted in 6.

- 6. Flexibility Variations:
  - a.) Vary flatwise flexibility at root from (4) hinge value to cantilever value in 4 increments
  - b.) Vary edgewise flexibility at root from hinge value to cantilever value in 4 increments
  - c.) Vary edgewise damping rate through 5 values to simulate lag damper action (5)

TABLE 2.7
HELICOPTER PERFORMANCE SCHEDULE FLOW CHART

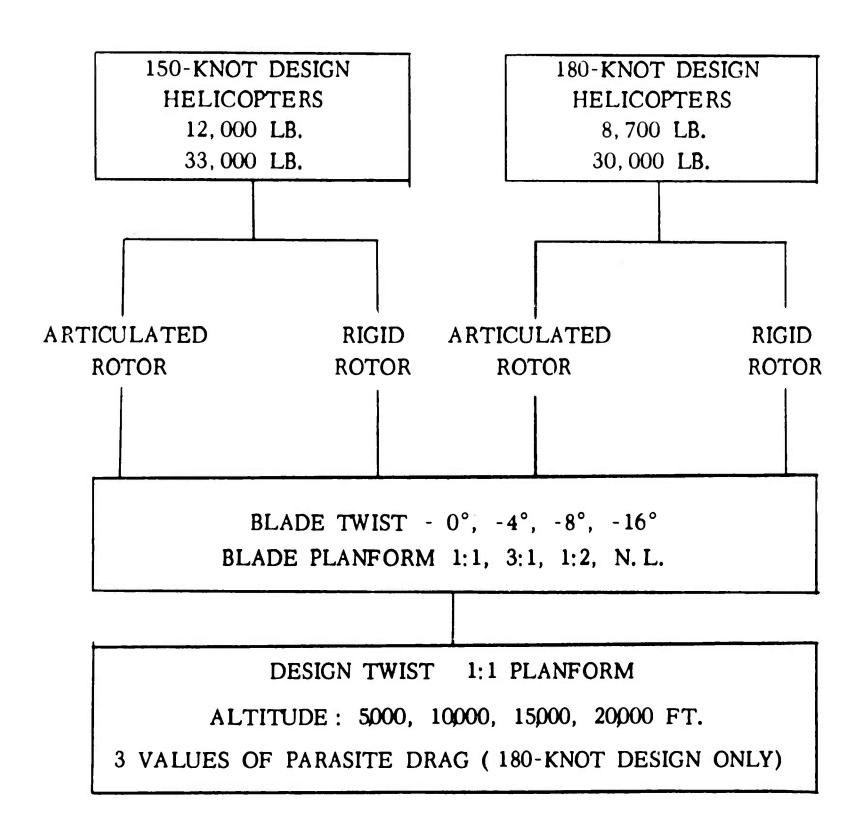


TABLE 2.8

COMPOUND PERFORMANCE SCHEDULE FLOW CHART

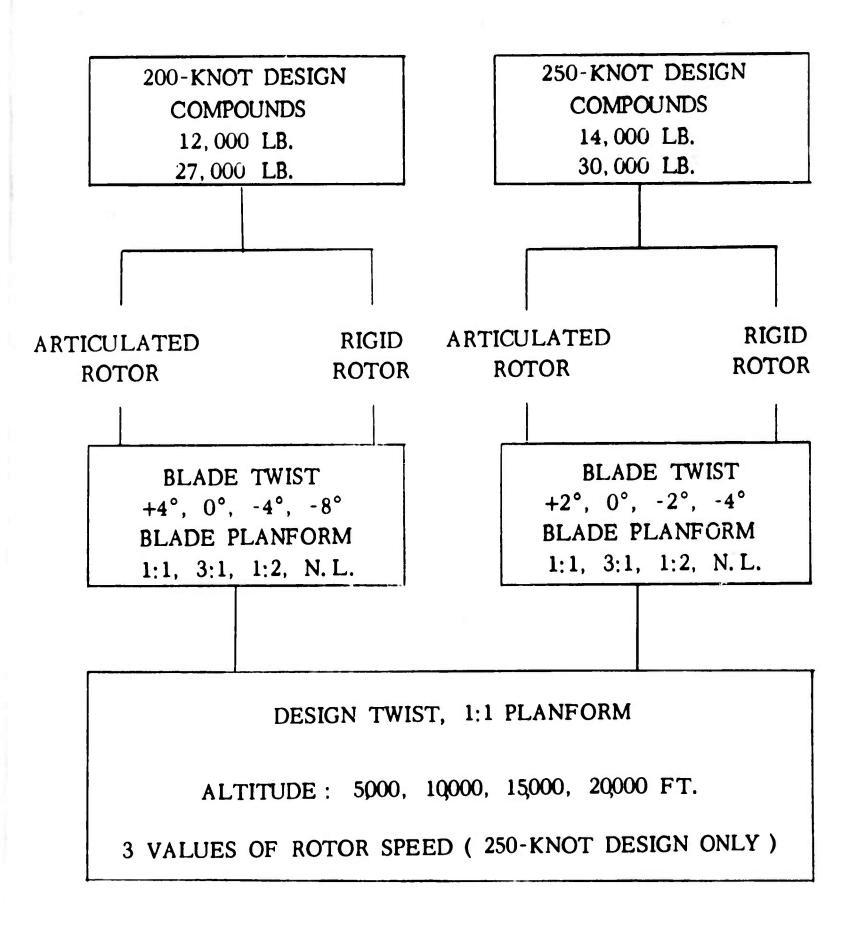
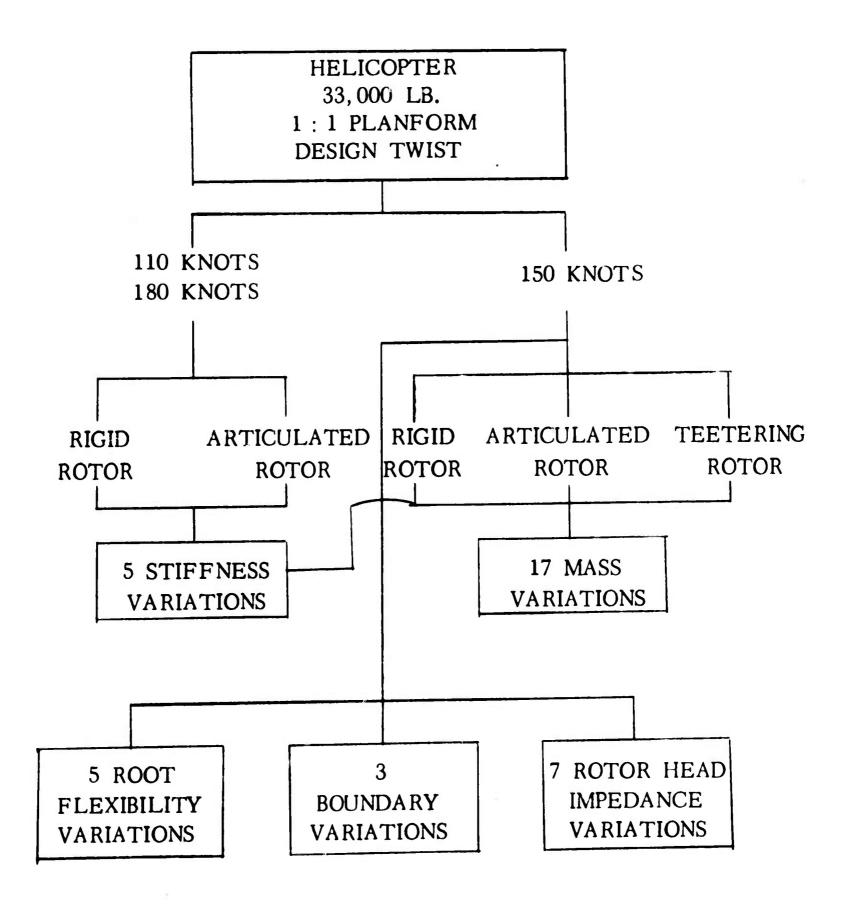
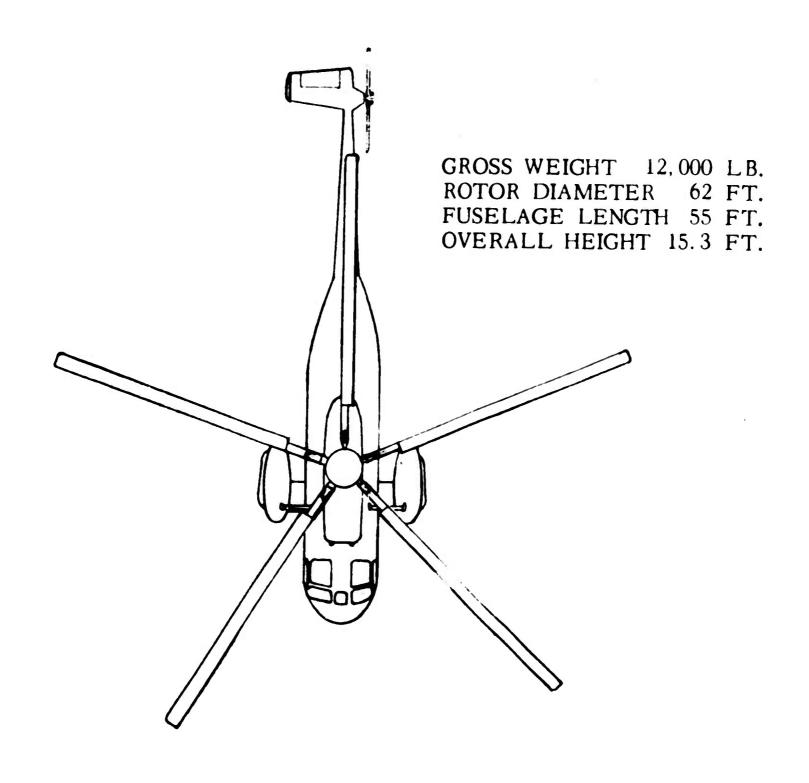


TABLE 2.9
STIFFNESS, MASS AND ROOT SCHEDULE FLOW CHART





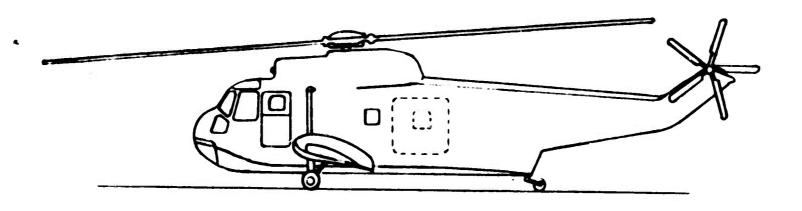
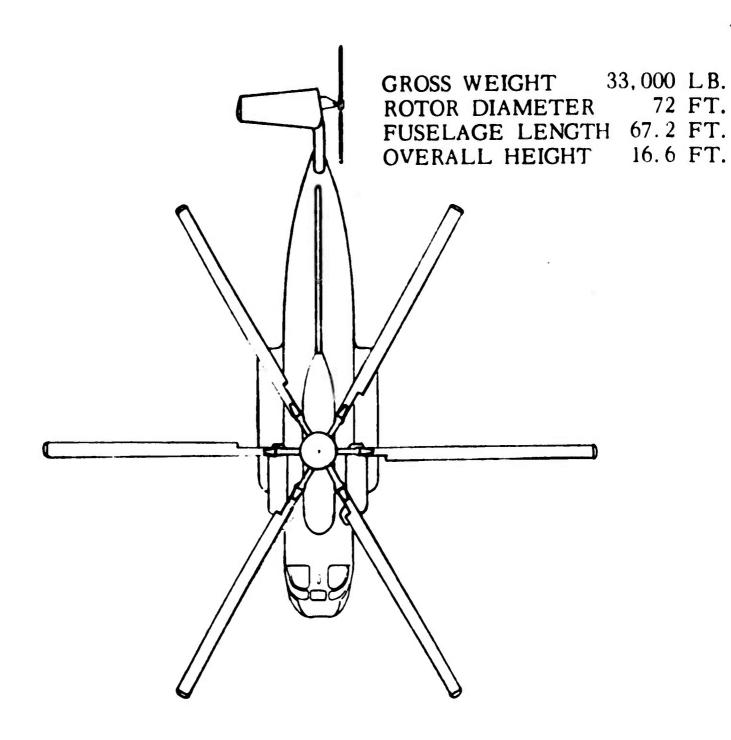


FIG. 2.1 H1 HELICOPTER



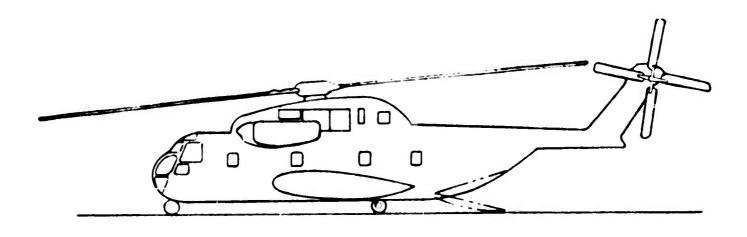
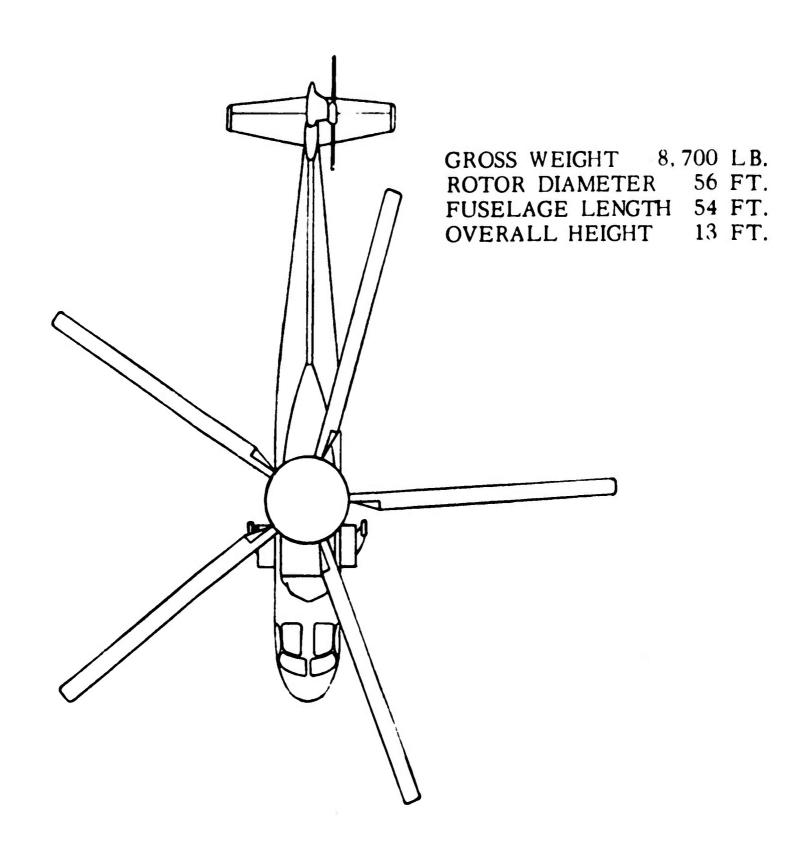


FIG. 2.2 H2 HELICOPTER



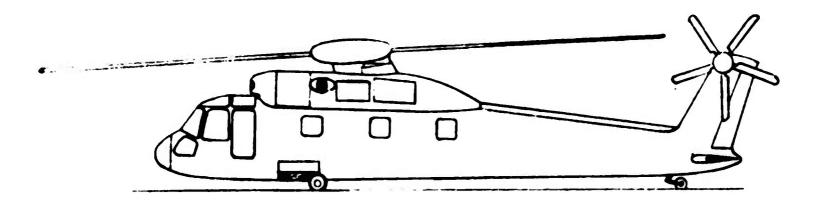


FIG. 2.3 H3 HELICOPTER

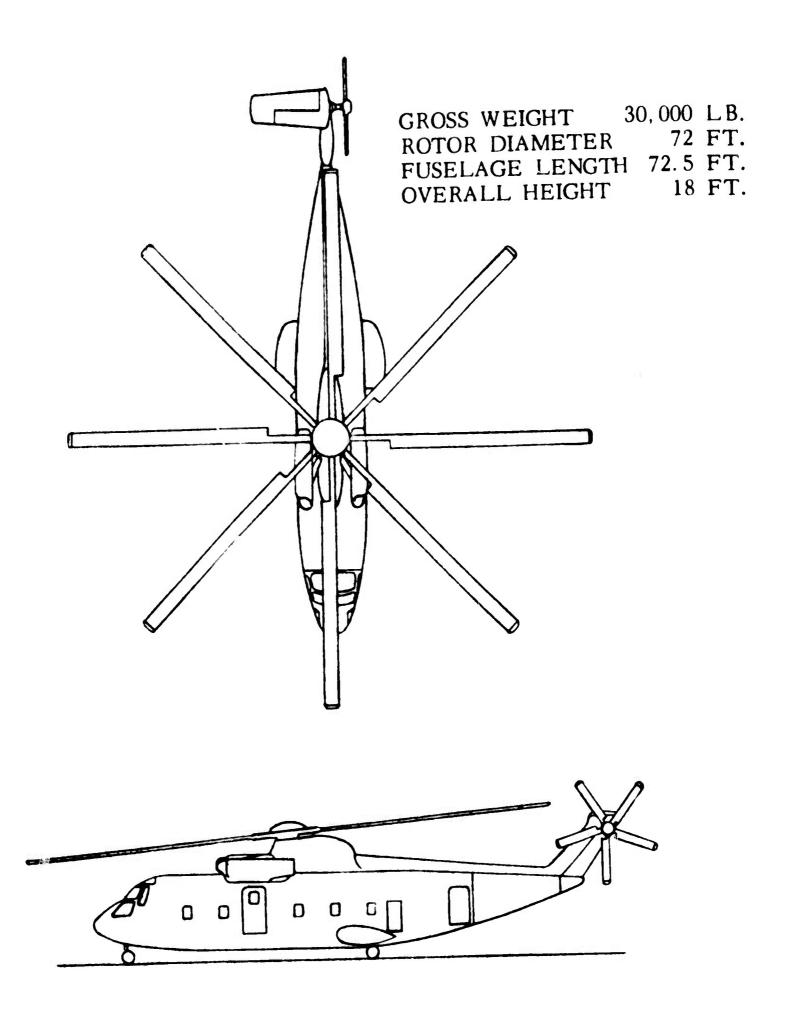
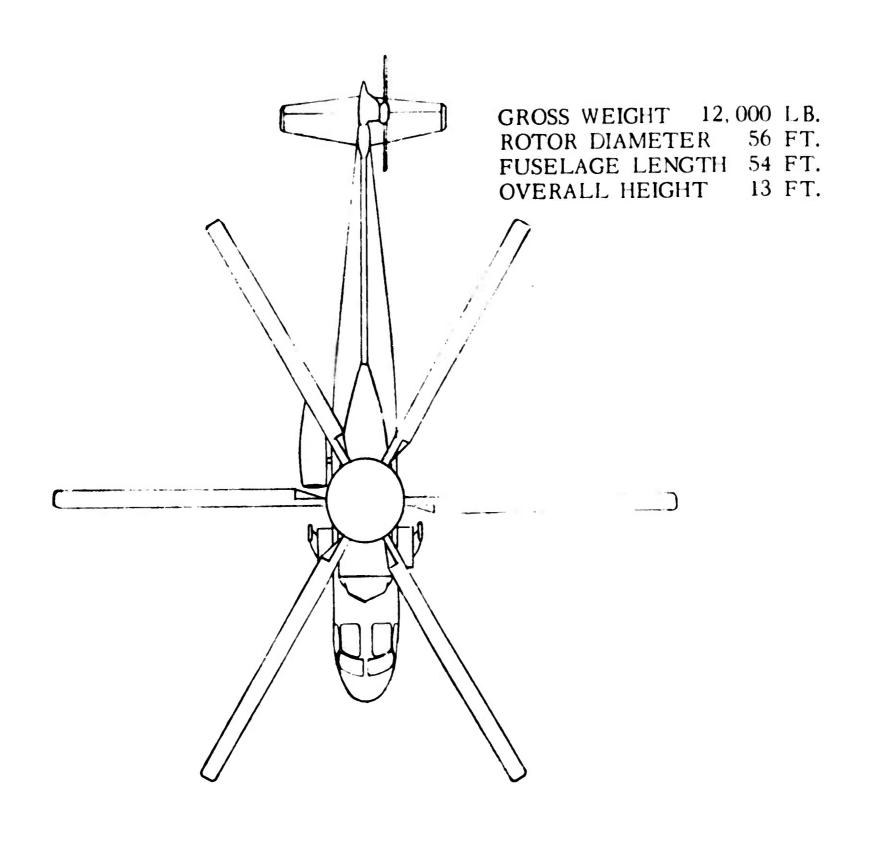


FIG. 2.4 H4 HELICOPTER



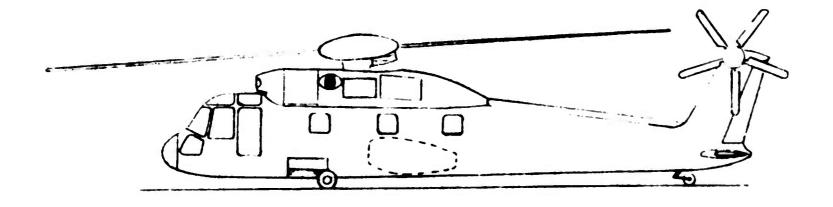


FIG. 2.5 C1 COMPOUND HELICOPTER

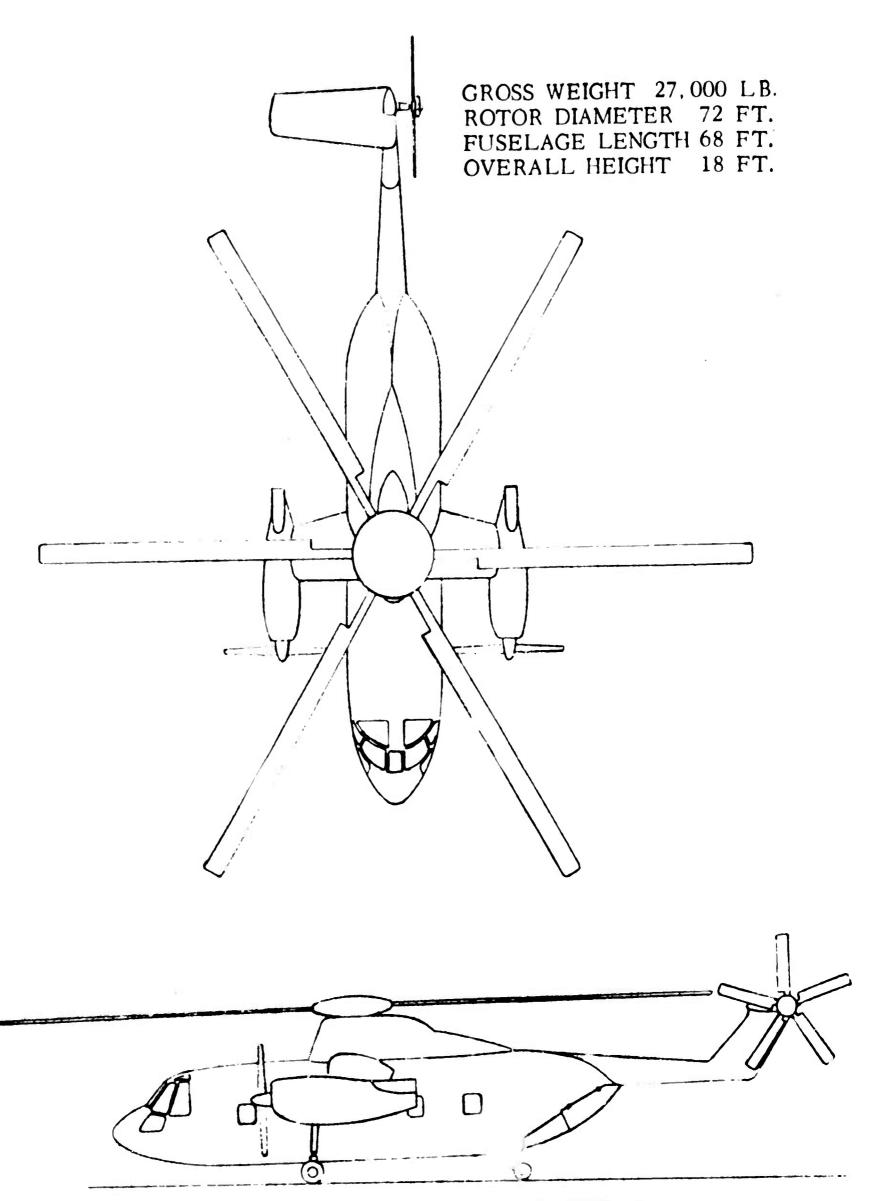
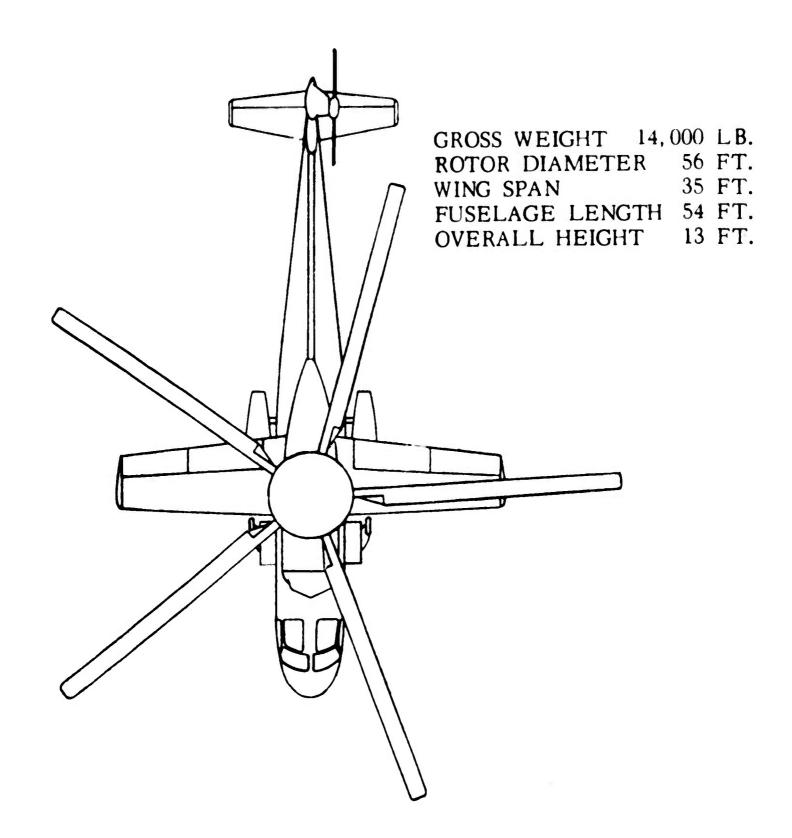


FIG. 2.6 C2 COMPOUND HELICOPTER



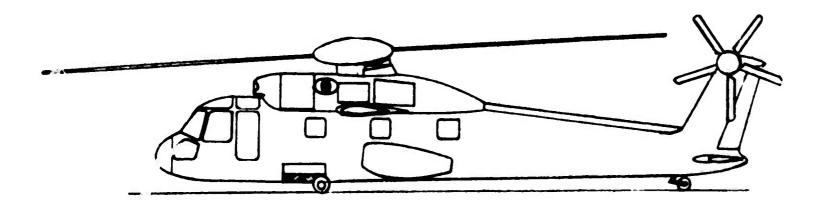


FIG. 2.7 C3 COMPOUND HELICOPTER

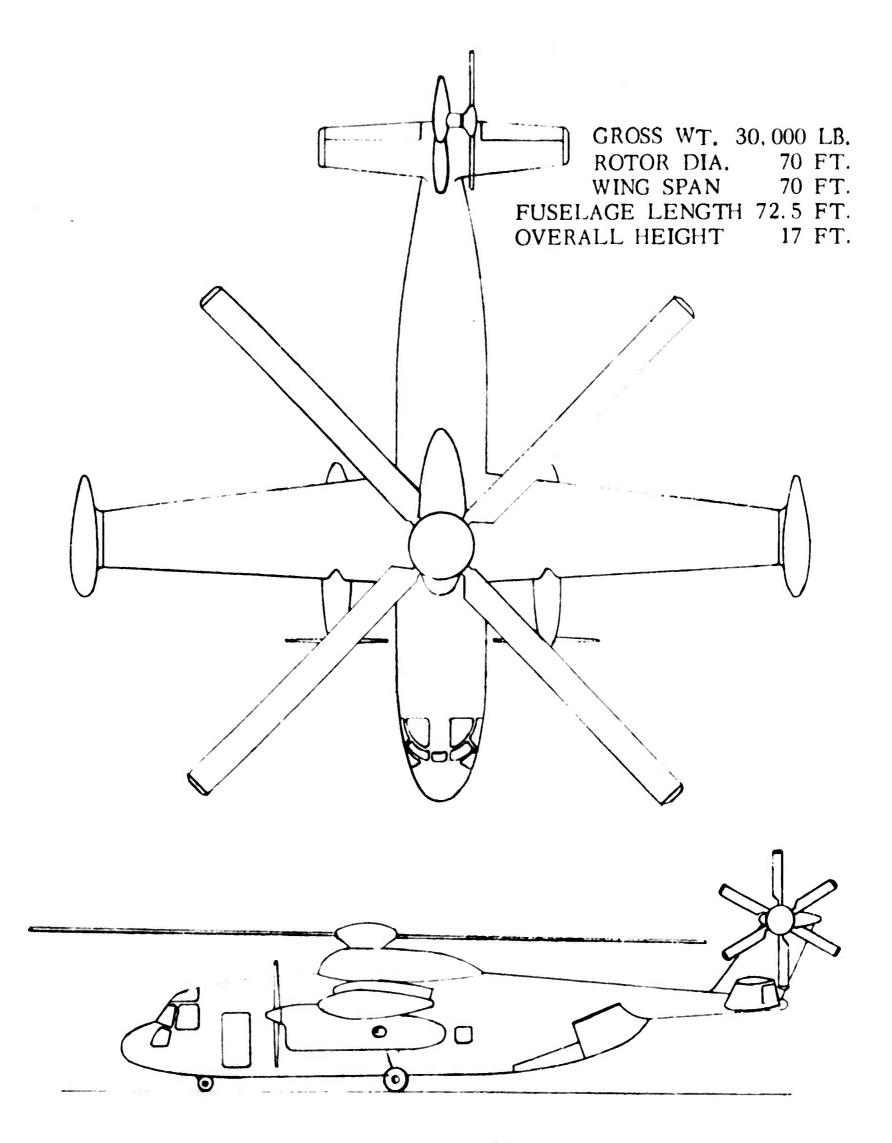


FIG. 2.8 C4 COMPOUND HELICOPTER

# BLADE PLANFORMS FOR AEROELASTIC STUDY

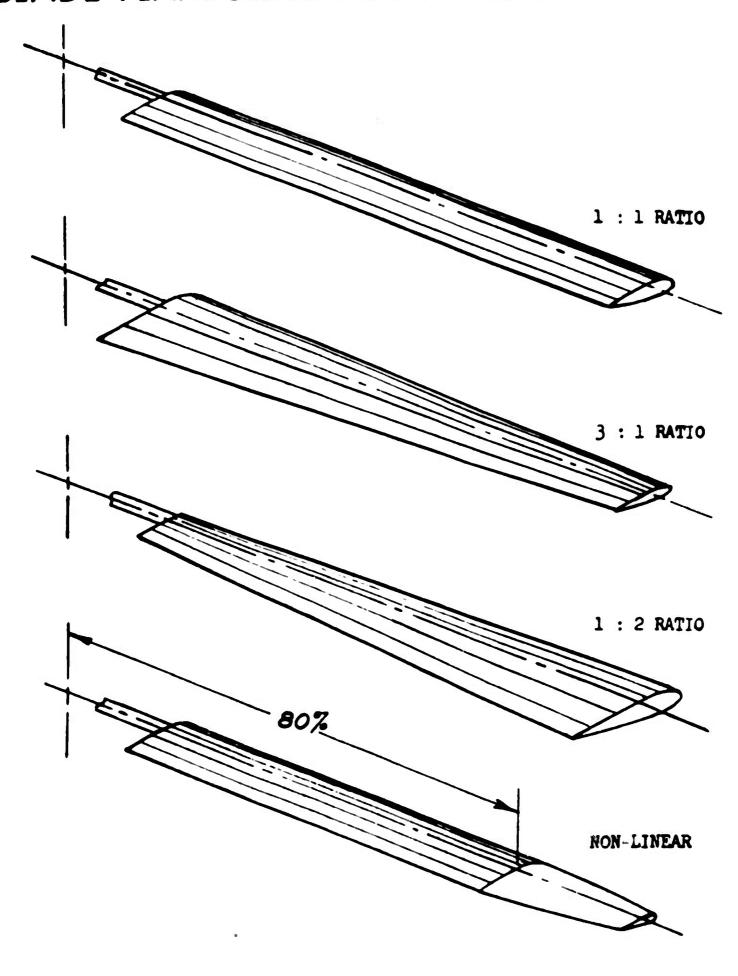


FIGURE 2.9

#### 3. AERODYNAMIC CRITERIA

Basic rotor parameters such as rotor diameter, tip speed, solidity, and number of blades were determined by the Sikorsky Aerodynamics Section using a performance method based upon blade-element strip analysis. Two-dimensional NACA 0012 airfoil data are used in the method, which takes into account both stall and compressibility effects. There are no small-angle assumptions. Also included are effects of flapping on blade-element angle-of-attack.

Figure 3. 1 presents a plot of parasite drag versus design gross weight for typical rotary-winged aircraft. It can be seen that the drag follows a (GW) 2/3 variation, corresponding to a wetted area correlation. A line representing a "clean" configuration is assumed for this study, since high-speed operation demands low drag and because Sikorsky experience indicates that drag clean-up through the use of rotor head fairings, retractible landing gear, and perhaps boundary-layer control is becoming more and more a matter of routine design consideration. For the compound helicopter, of course, the additional drag of a wing is added. Selection of rotor parameters to meet high-speed requirements was further based on past Sikorsky experience, as set forth in Reference 3.

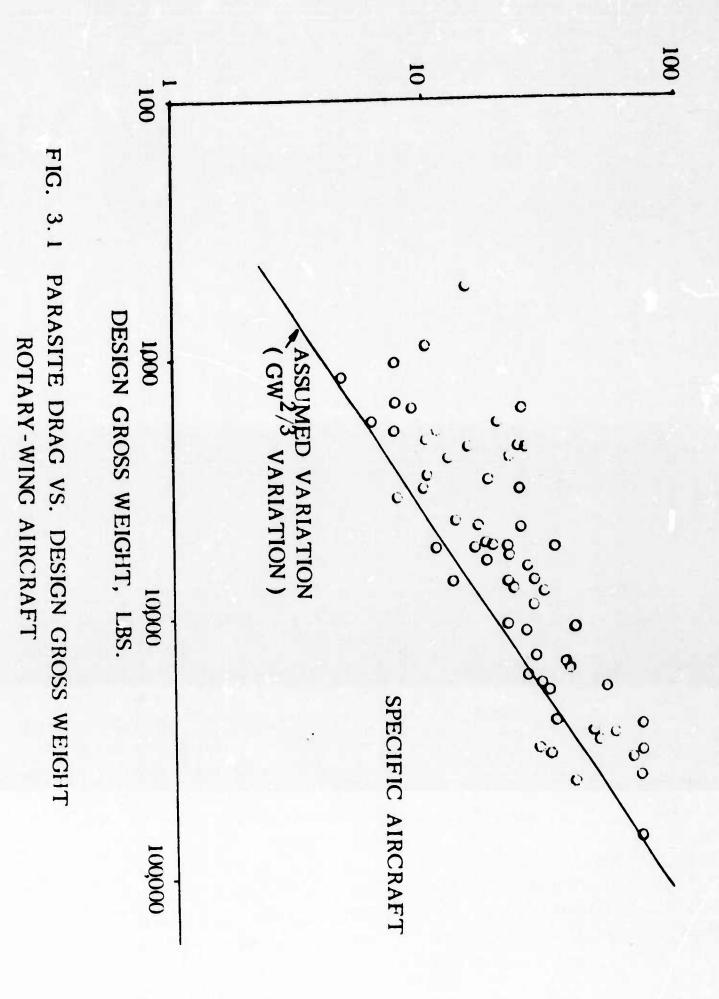
The following criteria were applied in the choice of rotor parameters:

- 1. Required powers are such that normal rated cruise power corresponds to military hover power OGE at 6,000 ft., 95°F.
- 2. The advancing blade Mach number does not exceed . 90 in order to avoid severe compressibility effects.
- 3. Blade aspect ratio is between 15 and 20 to minimize induced losses and to maintain reasonable blade weight.
- 4. For helicopters, rotor rpm is held constant for hover and cruise. For compound helicopters, rpm is controlled by Mach number limit (see 2 above).
- 5. Rotor CT/o for hover OGE at 6,000 ft. 95°F will not exceed . 10.

- 6. For compound helicopters, the amount of auxiliary thrust is equal to the sum of fuselage, wing, and rotor drag. This condition means that the control axis is slightly aft of vertical and that the shaft is vertical. The vertical shaft condition is maintained at all airspeeds so that fuselage attitude does not change.
- 7. For the winged compound helicopters, a wing aspect ratio of 6 was assumed. A wing of this planform and of the size required to produce the necessary cruise lift will cause a total vertical drag in hover of about 10% of the gross weight.

Gross weights in the range of 12000 and 30000 pounds are assumed for both the helicopter and the compound helicopter. A helicopter speed of 150 knots and a compound helicopter speed of 250 knots are felt to represent the normal cruise speeds attainable using present technology. High cruise speeds of 200 knots and 300 knots, respectively, are assumed in order to include what is felt to be a limit condition for the two configurations. For each variation in configuration, speed, and gross weight, the rotor system is optimized aerodynamically within the framework of the previously listed assumptions.

PARASITE DRAG AREA, FT. 2



## 4. BLADE DESIGN CRITERIA

Basic rotor parameters were determined as described in the previous section. These include tip speed, rotor diameter, blade chord, number of blades, and design twist. Based on these parameters, the Blade Design Section then developed structural characteristics for the articulated 1: 1 planform blades for each of the eight aircraft types to be studied. Blades were designed by standard Sikorsky procedures and met basic load requirements.

Structural design of the 1:1 planform blades was based on maximum flight and ground loading conditions. Static, fatigue, and centrifugal effects further defined structural requirements as well as unique mission profiles. Flight condition moments and loads required for structural analysis were defined from a tabular method developed by Horvay (Reference 4). Azimuthal summations were then obtained and applied to the structure to obtain corresponding stress levels. Ground condition criteria were determined from required gravity, wind, and torque considerations.

Extrapolation of uniform blades to those of other planforms (see Figure 2.9) assumed a conventional Sikorsky-type blade section (see Figure 4.1). The main load-carrying portion of the blade consists of an aluminum spar, D-shaped in cross section, that forms the leading edge of the airfoil. Trailing edge of the airfoil is formed of aluminum pockets of rib-type construction bonded to the back of the spar. Pockets are separate and are about 12 inches in length.

To extrapolate 1: 1 planform designs to those of other planforms, a study was first made of section growth trends for a D-spar section. The D-spar section was approximated as shown by Figure 4.1. From this, analytic expressions could be developed for section properties in terms of nondimensional parameters. Analytic expressions were then evaluated against actual production blade data at the 65% blade radius.

Several trends were noted: (1) The ratio of spar chord to blade chord was found to be essentially constant, and reasonably independent of overall blade aspect ratio and chord (see Figure 4. 2); and (2) The ratio of section depth to chord of the section was also noted to be constant (see Figure 4. 3). This left as the only significant parameter the ratio of average wall thickness to chord of the section.

Plots were then made of  $I_{XX}$ ,  $I_{yy}$ , and cross-sectional area versus section chord for various values of t/C. These are presented

in Figures 4. 4, 4. 5, and 4. 6. Circles represent typical D-spar design values at r/R = .65. These plots support the conclusion that section growth takes place along lines of constant wall thickness to spar chord ratio. The fact that actual design points do not lie near the same t/C line for all section properties is primarily attributed to changing numerical accuracy of approximations. But in all cases the growth trend is the same.

This conclusion formed the basis for extrapolation. Characteristics of separate planform blades were now extrapolated from 1: 1 planform designs by the following criteria:

- 1. At corresponding blade radial stations, cross-sectional area was held equivalent. By this means, blade weights and centrifugal stresses were kept equal. The only deviation permitted was when extrapolated wall thickness became small. Here, to avoid local spar buckling, a minimum value of 0. 15 inch was set.
- 2. Section properties were extrapolated based on the ratio of spar wall thickness to chord. Knowing chord and section area, this value could be determined and then used to calculate flatwise, chordwise, and torsional stiffness assuming a typical D-spar blade.

For rigid rotor systems, the blade root had to be specifically designed to meet the following criteria based on information provided by the Lockheed-California Company:

- 1. For planforms of aspect ratio greater than 18, a soft inplane system was used. This required the first inplane bending frequency to be between  $0.6\Omega$  and  $0.7\Omega$ . The inplane frequency was achieved by reducing root stiffness by removing material and attributing 15% of the frequency decrease to bearing flexibility.
- 2. For planforms of aspect ratio less than 18, a stiff inplane system was used. Here, blades were tuned so that the first inplane bending mode was near 1.4  $\Omega$ .
- 3. Flatwise flexibility of rigid blades was designed so that the second flatwise bending mode was sufficiently removed from n/rev.
- 4. Prelag and precone angles for the rigid blade were established from results of the articulated blade analysis at the design

late

airspeed. Steady coning and lag angles were taken from the articulated analysis, then used to establish root angles for the rigid blade in order to minimize steady root bending moments.

Section properties of blades considered in this study are tabuated in Appendix B, Tables B-1 through B-64.

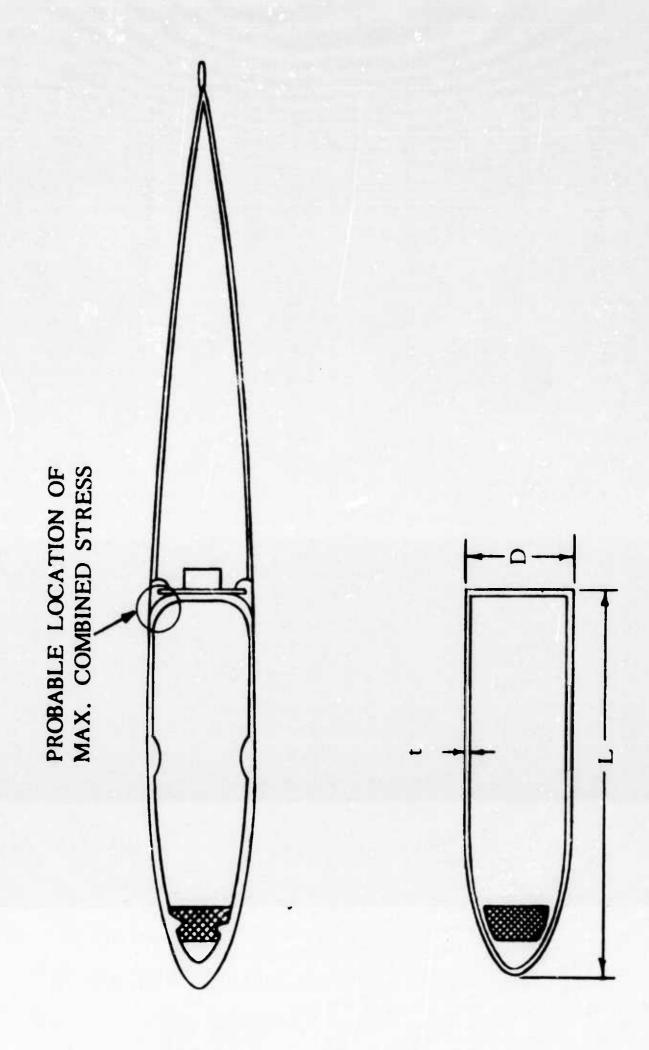
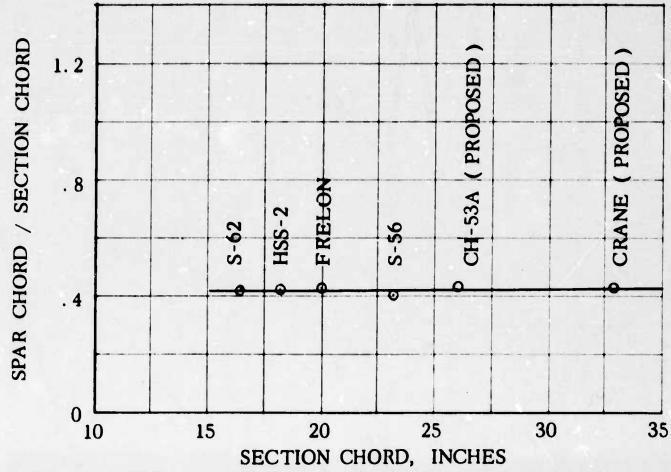


FIG. 4.1 SPAR CROSS-SECTION DETAIL



EFFECT OF CHORD ON L/C RATIO FIG. 4.2

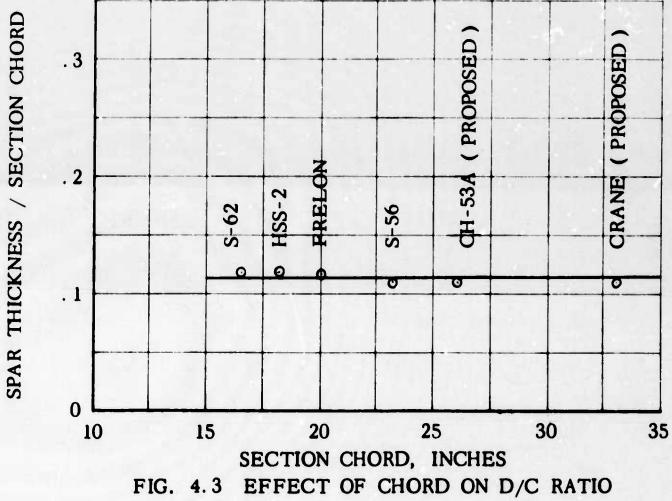
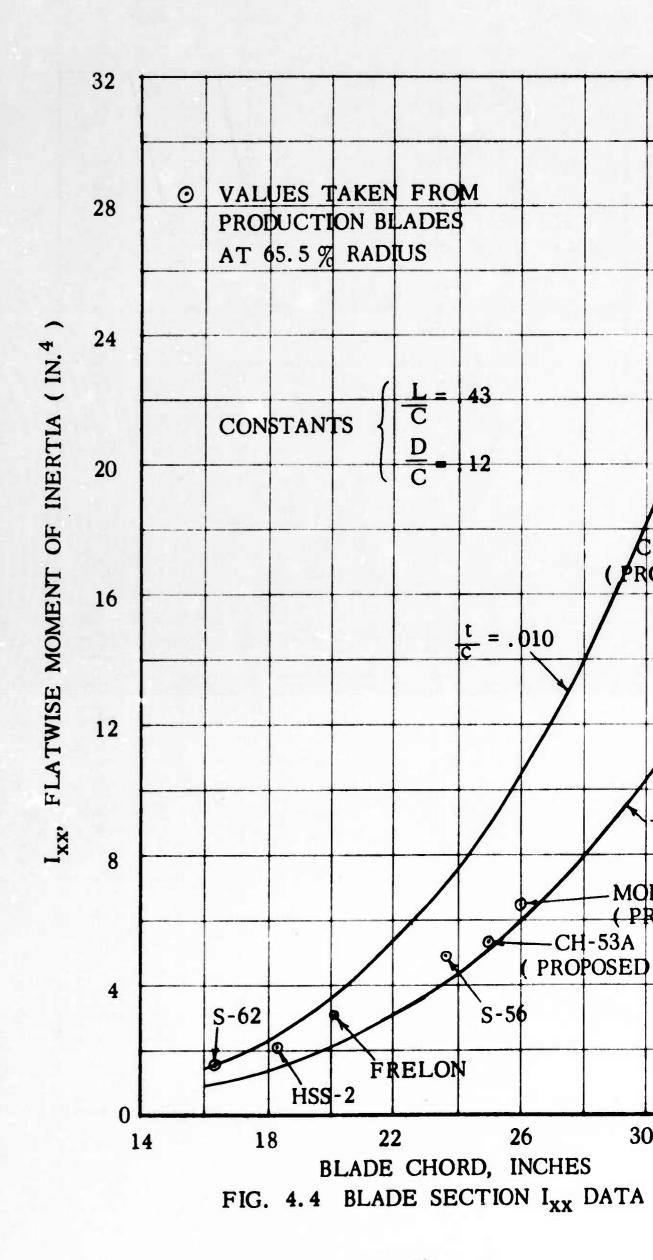
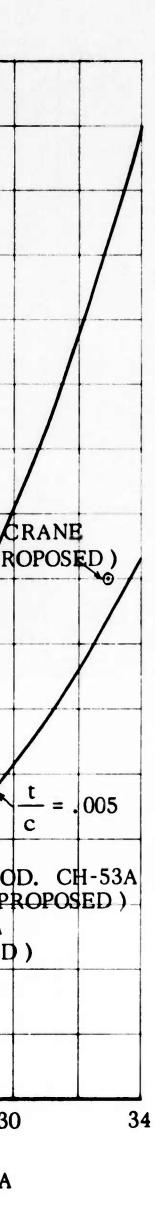
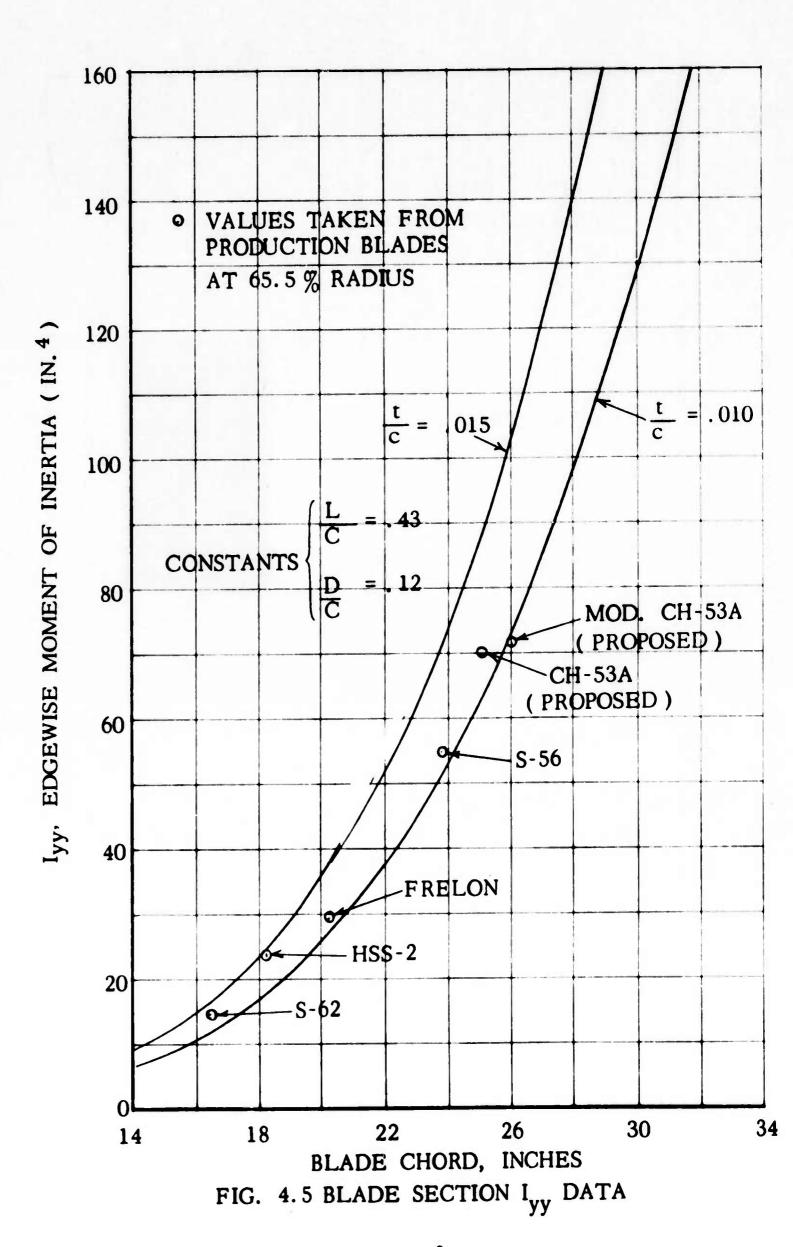


FIG. 4.3







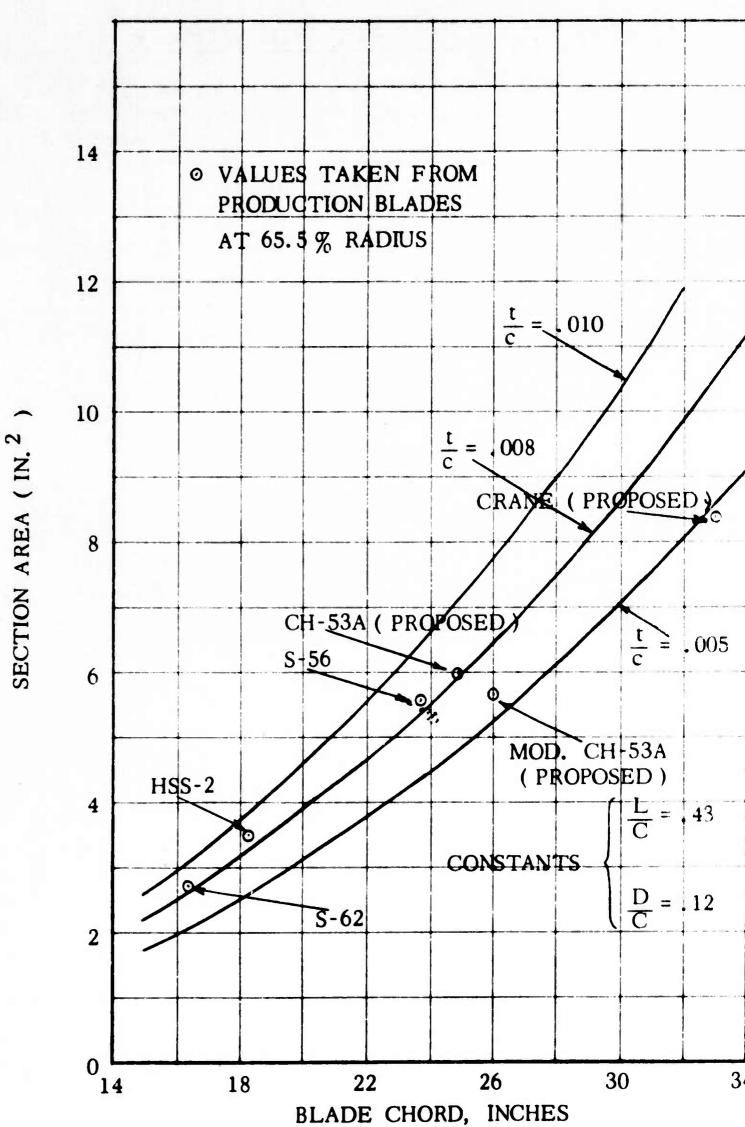


FIG. 4.6 BLADE SECTION AREA DATA

#### 5. DEVELOPMENT OF AEROELASTIC MODEL

To provide an adequate mathematical model for the study, the contractor extended an existing flatwise-chordwise blade dynamic analysis to include torsion. At the same time, the aerodynamic analysis was modified to compute aerodynamic pitching moments. Torsional coupling, while considerably complicating the analysis, introduced effects of torsional coupling on flatwise bending stresses. In addition, blade torsion and control loads could now be determined. Detailed descriptions of both the aerodynamic and earlier coupled flatwise-chordwise blade dynamic analyses are presented in Reference 1. Extension of the method to include torsion is given in Reference 2. Further results of correlation studies and preliminary results of the present aeroelastic investigation are set forth in Reference 5.

#### A. PROGRAM CHECKING

A systematic procedure was followed to check out computer programs for the aeroelastic study. Prior to calculating flight conditions, it was essential that hand checks and program checks match to eight decimal digits.

Initially, the aerodynamic program was recoded to provide the following refinements:

- 1. Calculation of aerodynamic pitching moments.
- 2. Closer tolerance on aircraft trim conditions gross weight, pitch and roll equilibrium.
- 3. Provision for retrimming the rotor after the blades have deformed in torsion.

For check-out, a test case was selected. Corresponding sections were checked out by side-by-side comparison with the original aero-dynamic program. New portions of the program were checked by hand calculations on a desk calculator.

The new blade forced response program was coded in three steps to include the torsion coupling. Each step was checked independently.

1. The first step was checked readily on a desk computer, for this step involved only blade rigid body motions.

- 2. The second step determined the steady coupled flatwise chordwise-torsional response of the blade. This was initially checked by zeroing torsion coupling and comparing results with the earlier program. Following this, the fully coupled response with torsion was checked. Output values for flatwise and chordwise shears, moments, slopes, and deflections, as well as torsional slopes and moments, were compared with hand-computed results by substituting into the basic equations. Hand calculations were done for a number of blade segments until all terms had been picked up. If answers did not check, actual machine procedure was followed by hand to isolate the source of error.
- 3. The third step determined the fully coupled vibratory response of the blade. Checking required first zeroing out the second step. With this complete, checking procedure was similar to the second step, but more time consuming, for equations were in complex form.

Test runs were made on the computer after checking equations of each step, as described above. Included in these checks, the blade was taken as rigid in torsion in the complete blade analysis. Results were again compared against the earlier flatwise-chordwise program.

# B. DESCRIPTION OF AEROELASTIC ANALYSIS

The method of aeroelastic analysis is based upon superposition of separate harmonics of blade-forced response, which result from response of the blade to individual harmonics of airloads. A detailed description of the method has been given in References 1 and 2; a brief description is given below.

# 1. Calculation of Aerodynamic Loads

For the helicopter to be analyzed, the gross weight, drag, speed, and rotor rpm must be given. Also for the blades, steady-state two-dimensional airfoil characteristics, structural stiffnesses, mass distribution, twist, and root retention must be specified. The rotor disk is considered to be moving at the proper forward tilt to provide enough propulsive force to overcome the net drag of the aircraft. It must also support the aircraft, and there must be sufficient cyclic pitch to keep the rotor in equilibrium. Certain simplifying assumptions are made to initiate the calculation, such as an estimate of the rotor drag and an estimate of the radial position of the resultant thrust vector. These approximations do not affect the final accuracy, for if

they are too far in error, this is remedied by a second or third iteration.

For a high-speed condition, constant inflow is taken. The blade is subdivided into up to 24 elements. For each of 36, 10-degree azimuth intervals, the blade is considered set at two blade angles. These angles bracket the expected blade angles. Blade-element aerodynamic lifts are then computed, from which the moment of the thrust about the flapping hinge is calculated as a function of blade angle and azimuth position. The cyclic pitch necessary to maintain the rotor system in equilibrium is then calculated by an iteration to enforce the condition that the first harmonic thrust moment about the flapping hinge is zero.

For calculation of aerodynamic loads, two-dimensional 0012 airfoil data are used. Compressibility effects are taken into account by using separate  $C_L$ ,  $C_D$ , and  $C_m$  versus  $\alpha$  curves for angles of attack from 0 to 30 degrees for Mach numbers up to 0. 95 in 5% increments. To define stall regions above angles-of-attack of 30 degrees, single  $C_L$ ,  $C_D$ , and  $C_m$  versus  $\alpha$  curves are taken from data in Reference 10.

Final determination of cyclic pitch yields angle-of-attack distribution, rotor drag, power required, location of resultant thrust vector, and thrust moments; and provides pitching moments, resolved thrusts, and drags on 24 blade elements for 10-degree azimuth intervals. A harmonic analysis is performed on this loading, and the steady plus the first seven harmonics of blade element loading (pitching moments, thrusts, and drags) are obtained in complex form.

# 2. Blade Dynamic Response

Individual harmonics of airloads are next introduced into the coupled blade dynamic analysis. This method is based upon an extension of Myklestad's analysis for rotating beams. There is provision for up to 24 flatwise, edgewise, and torsional degrees-of-freedom with coupling due to twist. Equations are in complex form to allow for aerodynamic damping and phasing of aerodynamic loads. Boundary conditions at the tip of the blade require that shears, moments, and torques are zero. At the root of the blade, boundary conditions are applied consistent with blade root restraint, whether articulated, teetering, or rigid. There is provision for a linear lag damper. Also, with torsion added, provision has been made for control system flexibility and damping.

Analysis for flexible blade dynamics with torsional coupling is done in three steps. In the first step, the blade is treated as infinitely rigid, and rigid body coning, lagging, and twisting are calculated. In the second step, using an iterative relaxation-type method, steady coupled flatwise-edgewise-torsional bending is computed. The iteration is initiated by using the blade slopes and deflections determined in the first step. In the third step, the first through the seventh harmonics of blade coupled responses are determined. Steady response values from the second step are used so that torsional coupling of vibratory forces times steady deflections and steady forces times vibratory deflections can be included.

Total forced response of the blade is next determined by superposition of separate harmonics of blade dynamic response. This yields the azimuthwise distribution of moments, torques, deflections, twist, and stresses at each of 24 blade stations for 10-degree azimuth intervals.

#### C. EFFECTS OF TORSION

The introduction of torsion, while considerably complicating the new aeroelastic analysis, gave new information on the effects of torsional coupling on blade flatwise bending stresses. In addition, it permitted calculating blade torsion and associated control loads.

Effects of torsion on rotor blade flatwise bending moments are presented in Figure 5. 1. Here, results of a fully coupled blade dynamic response calculation are compared with those of the method of Reference 1, which treats coupled flatwise-edgewise response but does not include torsion. In the case of the results shown with torsion, the rotor has been retrimmed for torsional deformation, and the calculation repeated. An increase in calculated flatwise bending moments is observed with introduction of the torsional degree-offreedom. Figure 5. 2 compares calculated results, with and without torsion, against flight test data for the S-58 (H-34) helicopter. Results suggest closer correlation with flight test data by taking torsion into account.

Given in Figure 5. 3 is a comparison between measured and calculated control loads for the S-58 at 110 knots. Measured data were taken from Reference 7. Computed control loads are seen to be somewhat higher than measured values, but the same general character of curve is observed in both measured and calculated results. The peak in the measured data at an azimuth position of 70 degrees was considered questionable, since this was defined

by one data point and was not evident in measured inboard blade torsion (r/R = .15) for the same flight condition.

Effect of forward speed on calculated helicopter control loads is illustrated by Figure 5. 4. Given are results for the S-61 helicopter at airspeeds of 100, 120, and 140 knots. As can be seen, the plots indicate a significant build-up in pushrod loads as airspeed is increased. Also noted and indicated by the plots is an increase in higher harmonic content with advance in airspeed.

# MODEL NO.S-58 11,800 lbs G.W., $\Omega$ =216 RPM V=110 KNOTS

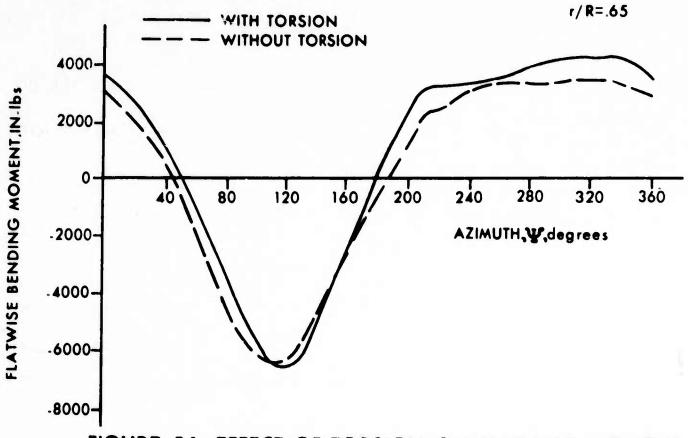


FIGURE 5.1 EFFECT OF TORSION ON FLATWISE MOMENT

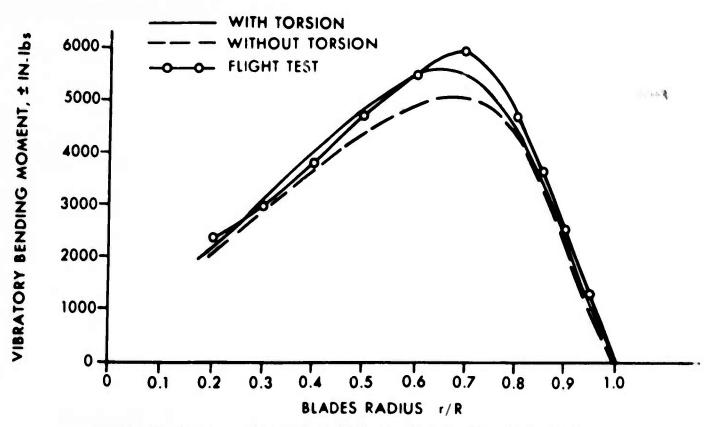


FIGURE 5.2 CALCULATED MOMENTS COMPARED WITH FLIGHT TEST

# 

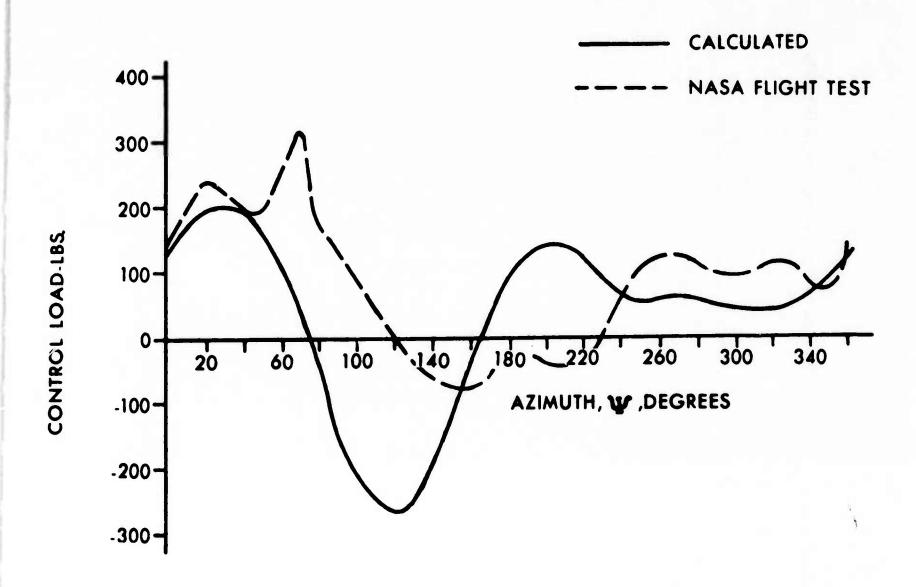


FIGURE 5.3 CALCULATED CONTROL LOADS COMPARED WITH FLIGHT TEST

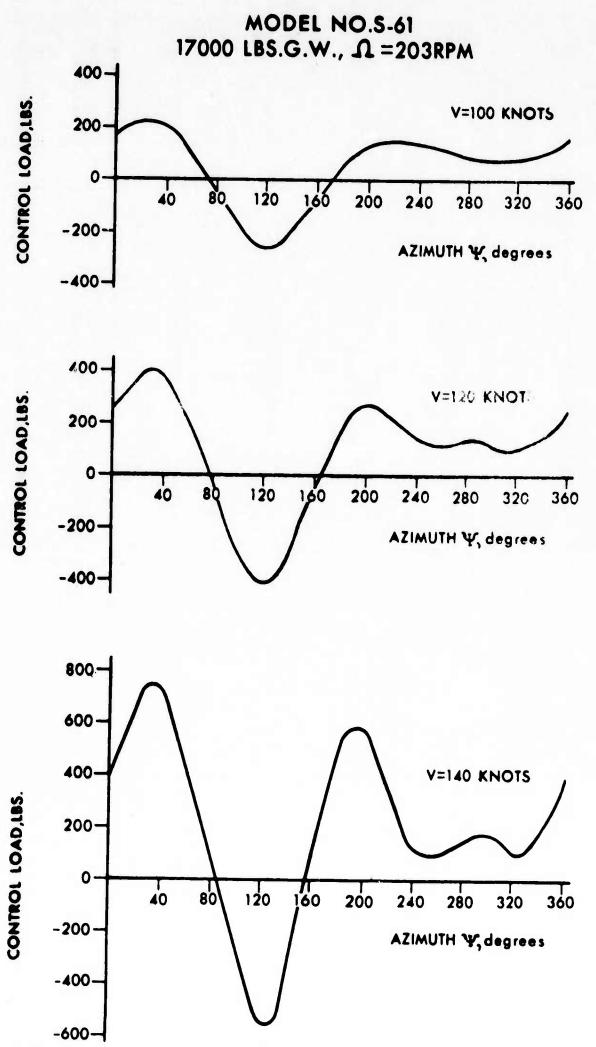


FIGURE 5.4 EFFECT OF FORWARD SPEED ON CONTROL LOAD

# 6. CORRELATION WITH FLIGHT TEST DATA

Using constant inflow, the method of analysis described shows good agreement with measurements in predicting performance. This is illustrated by Figure 6. 1. Here, calculated and measured power are shown to compare favorably for the S-61 at two gross-weight conditions. The computed values include power required for the tail rotor and accessory drives. Coefficients of drag for the blades were incremented by a  $\Delta C_{\rm b}$  = .002 to account for additional roughness of the actual blade compared to a polished wind-tunnel specimen. Note that good agreement is achieved even at low airspeeds where effects of variable inflow have been shown to be large. Comparisons also indicate that the method described provides performance results consistent with standard performance calculations in use.

Figures 6. 2 and 6. 3 compare calculated blade vibratory bending moments and stresses with flight test values for an articulated rotor helicopter. Given in Figure 6. 2 is a comparison of the radial distribution of one-half peak-to-peak bending moments against flight test data for the S-58 (H-34) helicopter. Data are shown for 110 knots. The test helicopter was instrumented by Sikorsky Aircraft under U. S. Army TRECOM contract. Flight tests were conducted by NASA at Langley Field, and preliminary results of tests were released in Reference 7.

Effect of forward speed on vibratory blade stresses and results of correlation are shown in Figure 6. 3. Here, flight test data taken at Sikorsky Aircraft are compared with calculated values for the S-58 at speeds above 100 knots. Each test point shown on the plot represents an averaging of data taken in three separate flights.

Correlation studies for a rigid-rotor helicopter were based on data furnished by the Lockheed-California Company for the CL-475 helicopter. Data included detailed information on blade stiffness and mass distribution. Also provided was a blade resonance diagram, a curve showing blade status deflection, and flight-measured vibratory bending moments along the blade at a number of airspeeds.

Results of earlier studies (References 1 and 2) have shown good correlation in predicting one-half peak-to-peak stresses at higher air-speeds using constant induced velocity. Thus, for correlation purposes, the highest airspeed was selected for which complete CL-475 data had been furnished. This was 100 mph. The blade was subdivided

into 20 segments in the fully coupled flatwise-chordwise-torsional analysis, allowing 60 degrees of freedom. The first step in the analysis was to run the calculation as a nonrotating beam to check analytical stiffness and weight characteristics against Lockheed's data for static deflection. Good agreement was achieved as shown by Figure 6. 4.

The second step in the rigid-rotor correlation program was to determine flexibility of spindle bearings at the blade root. This was achieved by varying the flatwise and chordwise root springs in the analysis until there was good agreement with Lockheed's blade resonance diagram as shown in Figure 6. 5. From this, effective springs of 1.75 million inch-pounds per radian and 4.00 million inch-pounds per radian were determined for respective flatwise and edgewise root stiffness. Differences between calculated and measured third flatwise modes shown by Figure 6.5 were attributed to motion of the rotor head. Test results had been obtained by shaking the hub with nonrotating blades where motion of the hub would tend to increase the natural frequency.

The third step in the correlation was to run the complete aeroelastic analysis at 100 mph using constant inflow. Here, the rotor was trimmed, cyclic pitch was determined, and aerodynamic loads were calculated. Harmonics of aerodynamic loads were then applied, and individual harmonics of blade response were superimposed. The radial distribution of calculated blade vibratory bending moments is shown to compare favorably with Lockheed's flight measured values in Figure 6. 6.

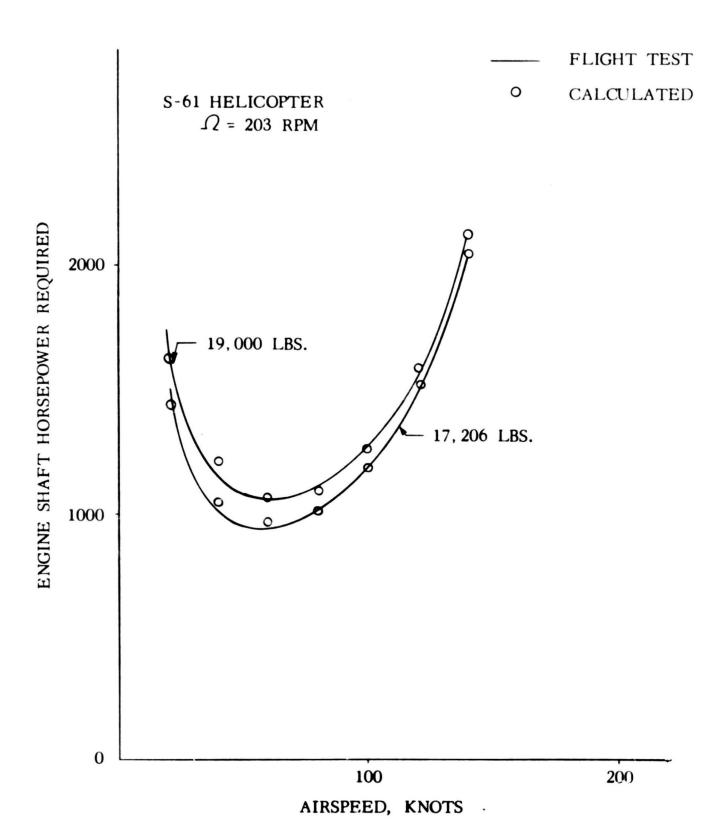


FIG. 6.1 EFFECT OF VELOCITY ON HORSEPOWER

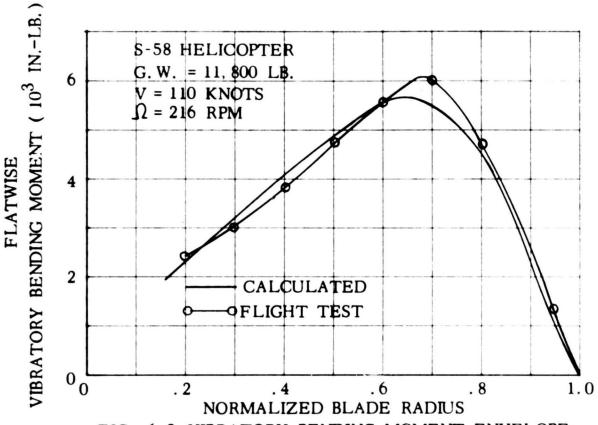


FIG. 6.2 VIBRATORY BENDING MOMENT ENVELOPE

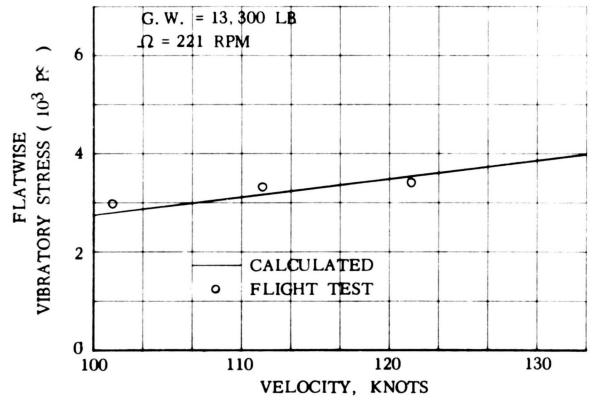
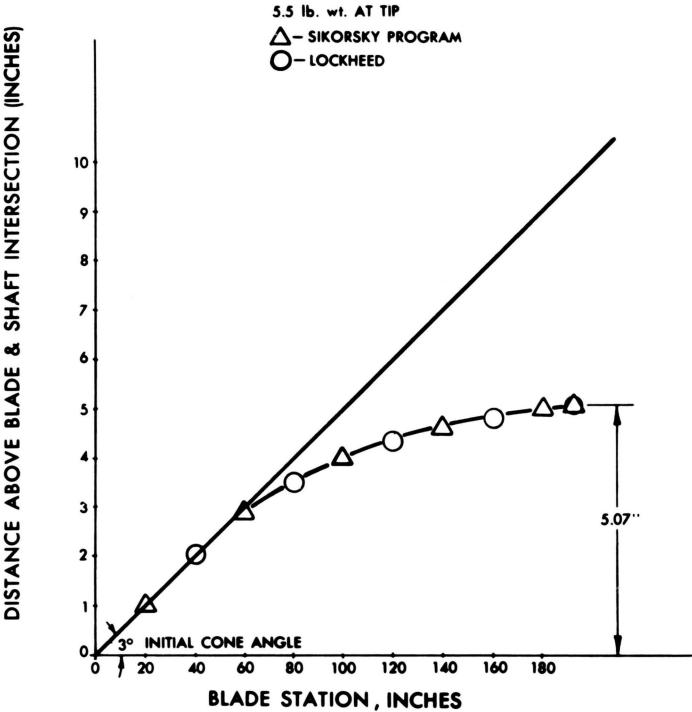
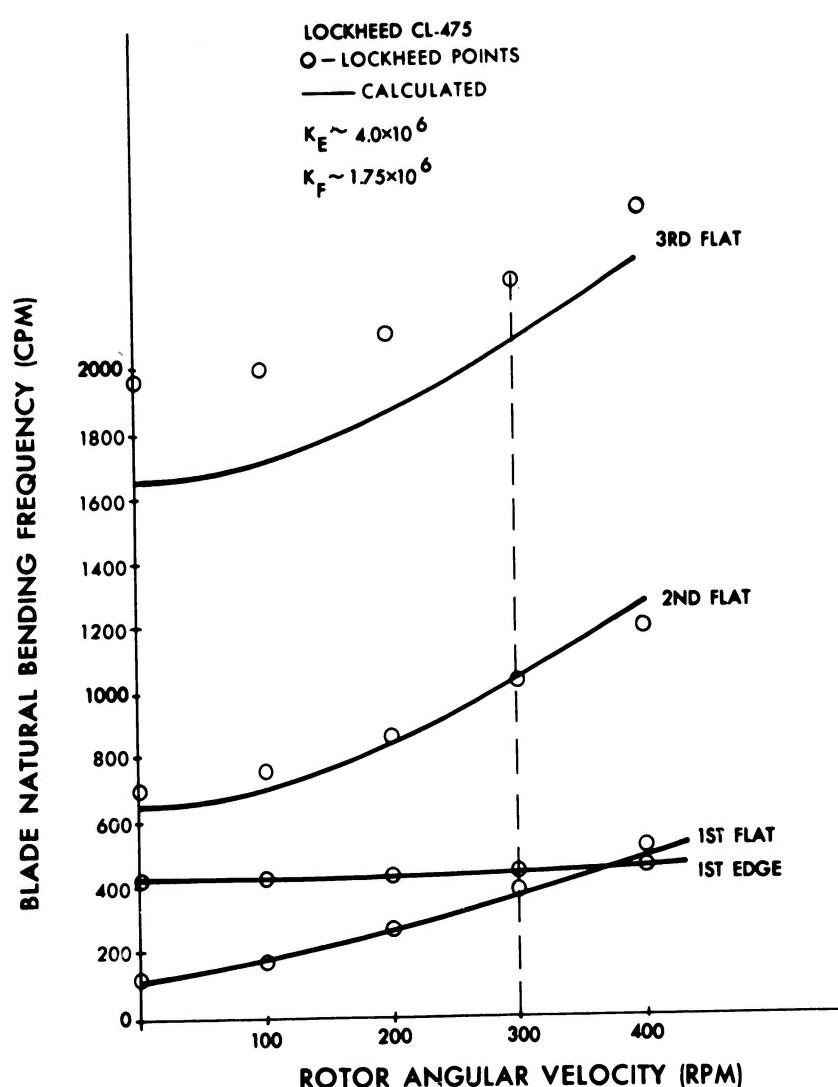


FIG. 6.3 EFFECT OF VELOCITY ON VIBRATORY BENDING STRESS

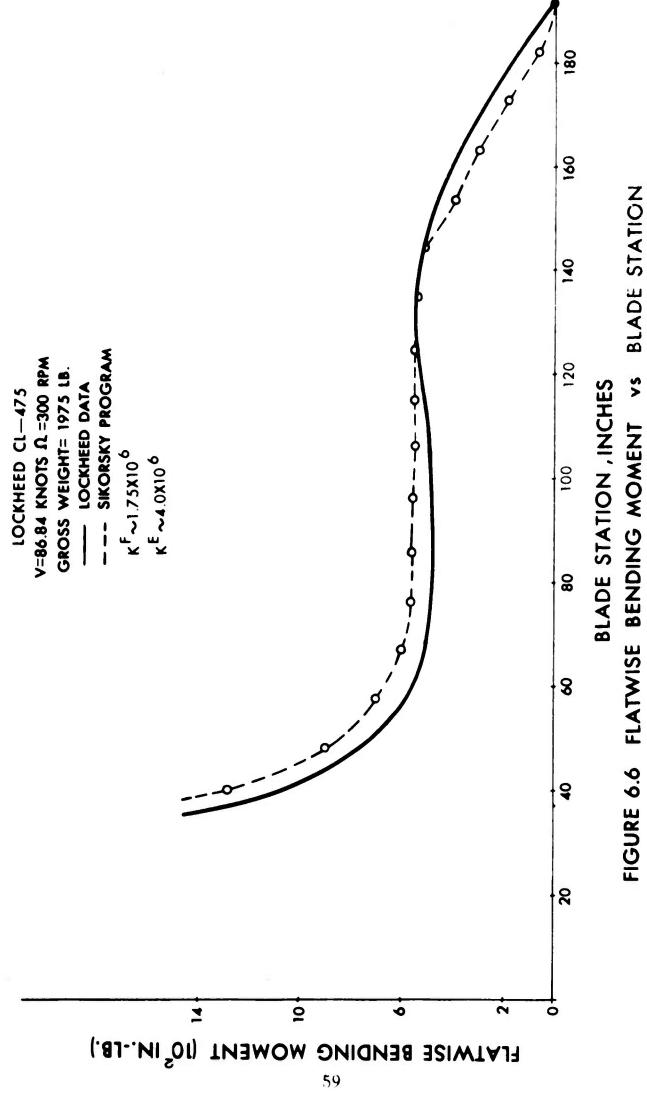


LOCKHEED CL-475

**BLADE STATIC DEFLECTION CURVE** FIGURE 6.4



ROTOR ANGULAR VELOCITY (RPM)
FIGURE 6.5 BLADE NATURAL FREQUENCY
vs ROTOR ANGULAR VELOCITY



## 7. TWIST AND PLANFORM VARIATIONS

Presented in Figure 2. 9 are the four blade planforms considered in the investigation. Tables 2. 2, 2. 7, and 2. 8 give the planform versus twist schedule followed. As shown by Figure 7. 1, only linear rates of blade twist were considered. Here, nominal twist refers to rate of twist based on total rotor radius and does not refer to actual twist in the spar of an offset blade, which is somewhat less.

Power curves for planform-twist variations reflect power required by the rotor. Neither tail rotor power nor accessory power has been added. Coefficients of drag for the blade were incremented by  $\triangle C_p = .002$  to account for blade roughness over that of a polished wind-tunnel specimen. This correction has been substantiated by test correlation of measured power (see Figure 6. 1).

Bending moment results represent maximum one-half peak-to-peak flatwise vibratory blade moments. Comparisons with flight test data indicate that this is the major contributor to vibratory blade stress, but it may not correspond to maximum combined stress on the spar section. Study of measured blade vibratory stresses for Sikorsky blades indicates that flatwise, chordwise, and torsional moments combine to give a maximum stress at the back corner of the D-spar section. Shown in Figure 4. 1 is a typical D-spar blade section. Locations of the neutral axis and probable point of maximum vibratory stress have been designated.

## A. ROTOR POWER CHARACTERISTICS

Variations in rotor power with change in blade twist and planform are given in Figures 7. 5 through 7. 20. Presented are results for the 16 rotor systems studied. General characteristics noted from these results are summarized schematically in Figure 7. 2, which is presented on the next page.

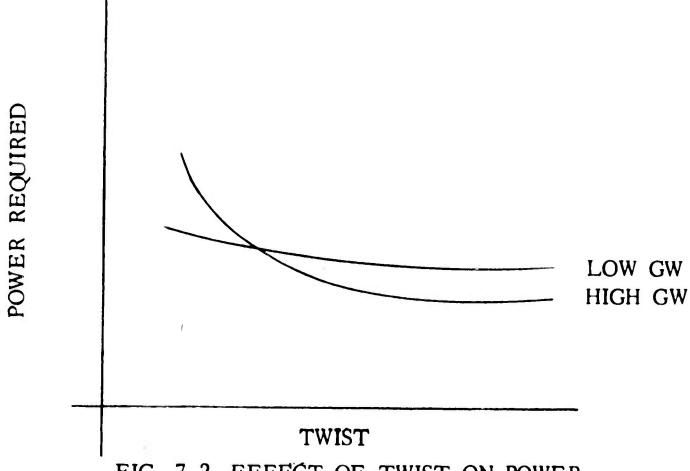


FIG. 7.2 EFFECT OF TWIST ON POWER

Conclusions from study of these characteristics are as follows:

- There is an optimum blade twist to minimize power 1. for the aircraft considered.
- The value of twist for minimum power will vary with 2. the aircraft's mission.
- 3. For the helicopters, optimum twist was found to be in the region of -8 degrees; for the jet compounds, in the region of -4 degrees; and for the winged compounds, in the region of 0 degrees. For winged compounds, variation of power with change in blade twist was found to be small.

With change in blade twist, gradual power variations were noted for the low-gross-weight designs. For the high-gross-weight aircraft, several cases of sharp power gradients were found with twist changes. Power variations were attributed to two effects:

> There was an outward movement of the steady aero-1. dynamic drag resultant acting on the blade with

decrease in negative blade twist. This is shown by Figure 7. 4, which plots location of resultant aerodynamic thrust and drag vectors with change in blade twist. Results are plotted for the H2 helicopter at 150 knots.

2. Figure 7. 3 shows the variation in magnitude of the resultant drag vector with change in blade twist for the same aircraft. Note that total drag increases as twist becomes more positive or negative about the minimum -4 degree point.

As illustrated by Figure 7. 2, there is a sharper power gradient with increased positive twist than with increased negative twist. Power is determined by the product of drag resultant times distance to center of rotation. With increased positive twist, Figures 7. 3 and 7. 4 indicate that both magnitude and distance of the resultant drag vector will increase, resulting in a sharp power gradient. With increased negative twist, magnitude of the vector increases but its location moves in, giving a more gradual power gradient.

Change in magnitude of the drag resultant with change in blade twist is attributed to the changing time-averaged L/D ratio for the entire blade. This results in an increase in drag, since the blade must maintain the same time-averaged lift coefficient independent of twist. The minimum point on the power-twist curve thus corresponds to that twist at which the blade is operating at its optimum time-averaged L/D ratio.

# B. FLATWISE VIBRATORY MOMENT CHARACTERISTICS

Presented in Figures 7. 21 through 7. 36 are maximum flatwise vibratory bending moments versus twist for the four blade planforms. Results are given for both rigid and articulated rotor systems and follow the schedule of Tables 2. 2, 2. 7, and 2. 8. It is interesting to note that the planform order from lowest to highest bending moments is fairly consistent between both gross weights, and rigid and articulated systems. For both gross weight machines, highest blade bending moments were for the relatively stiff 3:1 planform blade; lowest were for the nonlinear blade. The relatively flexible 1:2 blade, while showing low moments, would present design problems as a rigid rotor.

With variation in blade twist, flatwise vibratory moments followed general characteristics as shown by Figure 7. 37,

schematically below:

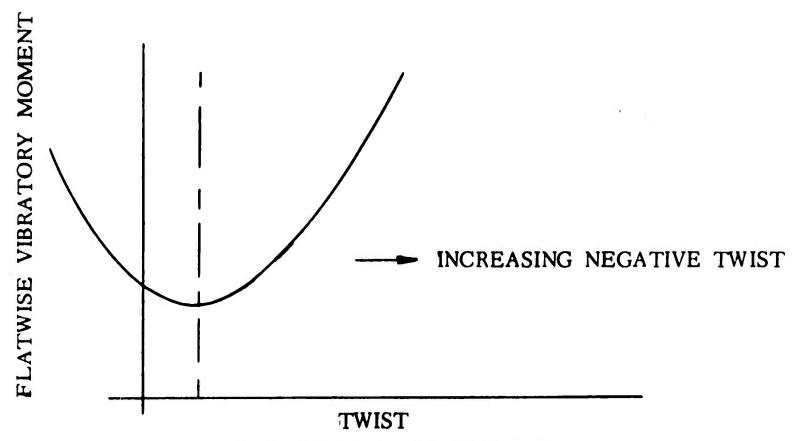


FIG. 7.37 EFFECT OF TWIST ON MAXIMUM BENDING MOMENT

From the curve it can be seen that there is a minimum vibratory moment for each blade design. For blade designs considered in this investigation, values of twist for minimum vibratory moment ranged from +2 to -2 degrees.

Shown in Figure 7. 39 are plots giving the radial distribution of one-half peak-to-peak stress for a typical articulated-rotor helicopter. Plots are presented for the H2 helicopter at 150 knots for a 1:1 planform blade at twists of 0, -4, -8, and -16 degrees respectively. Curves are typical of articulated blades with the maximum vibratory stress occurring at about two-thirds blade radius. Also, note that location of the critical blade station changes with change in blade twist.

Corresponding plots of the calculated time history of bending moment for the 0, -8, and -16 degree twists are given in Figure 7. 40. Observe that maximum negative bending stress occurs on the advancing blade at about  $\psi = 120$  degrees. Also, note that the

negative stress value at this azimuth is extremely sensitive to change in blade twist. Study of Figure 7. 40 supports the conclusion that increase in vibratory stress with increase in negative twist is primarily caused by increased negative bending moment on the advancing blade.

This conclusion is further supported by study of the aero-dynamic load distribution on the advancing blade. Figure 7. 41 plots the radial distribution of airloads on the advancing blade ( $\gamma = 90^{\circ}$ ) for 0, -8, and -16 degree twists. Note the appearance of negative lift regions on outboard blade sections as twist increases from 0 to -16 degrees. These outboard lift regions are responsible for the increased negative bending moments associated with larger negative twist. In turn, negative airloads are related to pitch trim requirements as described below:

- 1. Variation in blade control angle (reference r/R=0.70) with change in blade twist is plotted in Figure 7. 43). Results indicate that there is only a small change in collective pitch with blade twist since collective controls the thrust requirement, and this has been held constant for all twists. Also, observe that retreating blade control angle ( $\mathcal{V}=270^{\circ}$ ) remains fairly constant with twist, and is about that of the section stall angle. With negative twist, this means that blade element angles outboard of .70R are less than the control angle, while those inboard are higher. Or with increased negative twist, point of application of the resultant lift on the retreating blade moves in, giving a corresponding decrease in thrust moment.
- 2. Decrease in thrust moment with increased negative twist is plotted in Figure 7. 44 for both advancing ( $\psi$  =90°) and retreating ( $\psi$  =270°) blades. Thrust moment on the retreating blade was found to be close to the maximum attainable at this azimuth. Results showed that both halves of the rotor disk are attempting to balance total lift equally between them. If the control angle at  $\psi$  =270° degrees is increased above the value plotted, outboard blade sections have higher angles of attack, move further into stall, and lose lift. With decreasing control angle at 270 degrees, outboard blade angles decrease and there is reduced lift on the blade.
- 3. The requirement for rotor trim in the calculations was that there be no pitching or rolling moments in fixed

coordinates. Therefore, associated with decreased thrust moment on the retreating blade, there must be a corresponding decrease in thrust moment on the advancing blade as shown by Figure 7. 44. At the same time, total thrust on the advancing blade increases to compensate for less of lift on the retreating blade. Here, advancing blade inboard elements must increase lift to offset negative lift on outboard sections. The rotor fails to meet trim requirements when inboard sections of the advancing blade can no longer make up for lift lost on the retreating side. These trends can be seen in the airload distributions on advancing and retreating blades for various blade twists as shown by Figures 7. 41 and 7. 42.

4. In conclusion, increased negative twist unloads the retreating blade and loads the advancing blade. Due to pitch trim requirements, the advancing blade cannot carry the additional lift on the most efficient outboard panels. Instead, it must move the lift well inboard. The resulting one-per-rev load dissymmetry is the aerodynamic cause of increased blade vibratory stress with increased negative twist.

Figures 7. 45 through 7. 47 present effects of blade twist on combined aerodynamic and inertia loads, and resulting blade deflections and moments. Plotted in Figures 7. 45 and 7. 46 are radial distributions of aerodynamic (shown dotted) and inertia loading for 0 and -8 degree twist blades for the H2 helicopter. Load distributions are given for azimuth positions of maximum negative and positive bending stress. The contribution of blade response to total applied load is shown by the difference between applied and aerodynamic loadings. Figure 7. 47 shows schematically corresponding outboard deflections and moments for each blade at the azimuth position of maximum negative stress. Note the larger deflections of the 0 degree twist blade due to more heavily loaded blade outboard sections. Also, note the 20% radius shift in location of the critical blade station. Observe that both blades have about the same positive moment due to applied flatwise loading, but negative moment of the -8 degree twist blade is greater due to centrifugal forces.

So far, discussion has centered on understanding increased vibratory stress with increased negative twist. Figure 7. 37, which gives general characteristics of stress-twist variations, also shows increased stress as twist becomes more positive.

Analysis of results indicates that this is due to increased positive moment on the retreating blade rather than increased negative moment on the advancing blade. As twist becomes more positive, the retreating blade takes on more load. In other words, minimum on the stress-twist curve of Figure 7. 37 is that point at which best load sharing is achieved as related to stress. As twist becomes further positive, the retreating blade moves into stall. At this point the advancing blade once again assumes the additional load.

Results of stress-twist variations for rigid rotor designs showed aerodynamic trends similar to articulated systems, but as expected, resulting blade responses were considerably different. Given in Figures 7. 48 and 7. 49 are the radial distributions of airloads for 0 and -8 degree twist blades for the H2-R. Results are plotted for both advancing ( $\psi = 90^{\circ}$ ) and retreating blades ( $\psi = 270^{\circ}$ ). Comparison of these plots with those of Figures 7. 41 and 7. 42 for the equivalent articulated blade indicates little difference in airload distribution.

Presented in Figure 7. 50 are azimuth histories of bending moment at the critical blade station for the same rigid blade. Comparison with azimuth plots (Figure 7. 40) for an equivalent articulated blade shows widely different harmonic contents. Variations are attributed to differences in modal response, differences in aerodynamic damping, and wide separation of location of critical blade station. For the H2-R 0-degree twist blade, one-half peak-to-peak bending moment is defined by the difference between moments at  $\psi = 160^{\circ}$  and  $\psi = 260^{\circ}$ . Radial distribution of vibratory bending moments is given in Figure 7. 38. For rigid blades, maximum vibratory moment generally occurs at the blade root.

## C. EDGEWISE VIBRATORY MOMENTS CHARACTERISTICS

Variations in edgewise vibratory moments with twist and planform changes are presented in Figures 7. 51 through 7. 54. Shown are results for the H1, H1-R, H2, and H2-R helicopters. There is a trend with twist similar to that observed for flatwise bending moments (see Section 7-B). Note that edgewise moment minimum values occur at higher negative twist than for corresponding flatwise minimums. There are several significant variables which affect blade edgewise moments. These include:

## 1. Edgewise Tuning for Rigid Rotors

Lockheed's design criteria (Section 4) take into account the

high sensitivity of edgewise moment to the blade's first inplane bending frequency. Proximity of this mode to one-per-rev results in excessively high chordwise moments at the blade root. Here, blade resonance becomes more critical than for flatwise moments since there is little aerodynamic damping to attenuate amplification. Figure 10. 4, which plots the effect of tip weight, clearly indicates this sensitivity for a rigid blade. The sharp continuous reduction shown for edgewise stresses is due to detuning the first edgewise mode. The rigid blade in this case (aspect ratio = 18) was designed for  $\omega_r^r = .65 \Omega$ . Added weight brings this mode further below one-per-rev.

#### 2. Lag Damper Characteristics for Hinged Blades

For the investigation, a linear lag damper constant was assumed in the analysis. This provides a damping moment in proportion to the blade angular hunting velocity. Actual blade dampers used for conventional helicopters are difficult to simulate analytically. Here, damping is provided by hydraulic fluid passing through an orifice. This results in damping proportional to velocity squared. Also, these dampers often provide a relief valve to limit blade stresses, which introduces a sharp cutoff at a specified damper force. Detailed correlation of calculated edgewise moments with flight test requires that such effects ultimately be taken into account.

## 3. Blade Counterweights

Mass-balancing blade counterweights (see Figure 4.1) were considered as being attached to the blade section but nonstructural in the analytic study. In actual practice, weights may be restrained against radial motion by a plate at the blade tip. A concentrated force is then produced forward of the elastic axis at the tip. This results in a large steady edgewise bending moment being applied to the blade.

## D. PLANFORM CHARACTERISTICS

Variation in blade planform results in two significant effects. There is a change in radial distribution of airload due to change in chord with blade radius. Also, there is a shift in blade response characteristics due to mass and stiffness changes associated with chord variation. These are discussed separately as follows.

## 1. Aerodynamic Loading

Developed below are equations which relate blade twist

and planform. They give the twist required on a 1:1 tapered blade to reproduce the blade loading on a blade of arbitrary chord and twist distribution.

Then: 
$$dL(\mu\psi) \sim \frac{1}{2} e^{\sqrt{(\mu\psi)}} dC \propto (\mu\psi) C(\mu) \dots \dots (1)$$

Setting up a ratio for the blades:

$$1 = \frac{\frac{1}{2} (h \psi)}{\frac{1}{2} (h \psi)} = \frac{\frac{1}{2} \rho \sqrt{(h \psi)} \frac{d \zeta}{d \alpha} \alpha (n \psi) C(h)}{\frac{1}{2} \rho \sqrt{(h \psi)} \frac{d \zeta}{d \alpha} \alpha (n \psi) C(h)} \cdots (2)$$

If airfoil sections are the same for each blade:

$$\frac{d\zeta}{d\alpha} = d\zeta \qquad (3)$$

Or, the required angle-of-attack distribution (uniform blade) is:

Also: 
$$\frac{\alpha_{1:1}(n\psi) = C(n)}{C_{n}} \alpha(n\psi) \dots (4)$$

But for equivalence of airloads:

$$(\theta + \phi)_{ii} = \theta + \phi \qquad (6)$$

And required twist for the uniform blade is:

$$\beta_{r}(h)_{i,j} = (\Theta + \phi) \left[ 1 - \frac{C(h)}{C_{i,j}} \right] + \frac{C(h)}{C_{i,j}} \beta_{r}(h) \dots (7)$$

Equation 7 shows that equivalence of twist and planform is not only determined by chord ratios but also depends upon  $(\theta + \phi)$ . Values  $(\theta + \phi)$  are functions of both azimuth,  $\psi$ ,

and forward speed, V. However, preliminary results of these studies indicate that the azimuth variation may not be significant in matching low harmonics of airloads for twist-planform similarity.

This is shown by Figures 7. 55 through 7. 57. Plotted in Figure 7. 55 is the change in location of the resultant steady thrust vector with change in blade twist for a 1:1 planform or uniform blade. Results are presented for the H2 helicopter at 150 knots. Also shown on the plot are locations of the thrust vector for -8° twist, 1:2 and 3:1 planform blades. The 1:2 taper, -8° twist blade is noted to be nearly equivalent to a 1:1 taper, -6.5° twist blade. Similarly, the 3:1 taper, -8° twist blade compares closely to a 1:1 taper, -10.8° twist blade.

The equivalence is further reflected in calculated control angles at this airspeed. Figure 7. 56 plots variation in collective and cyclic pitch blade angles versus blade twist for the uniform blade. Also shown on this plot is corresponding control angle for the 1:2 planform blade. Note that the twist equivalence value for this blade is about the same (-6.5°) as on the thrust vector location plot.

Even more interesting is the near match of steady and first harmonic blade loading. This is shown by Figure 7. 57. Compared are the load distributions for a  $-6^{\circ}$  twist, 1:1 planform blade and the  $-8^{\circ}$  twist, 1:2 planform blade. (The  $-6^{\circ}$  twist, 1:1 planform blade was the nearest parametric data point to the selected  $-6.5^{\circ}$ , 1:1 blade, which had been run in the study.) Note that not only do steady airload distributions agree, but also both sine and cosine first harmonic distributions are approximately the same.

# 2. Blade Response

While planform and twist can be related to determine equivalent airload distributions, the resulting blade responses will differ. This is due to changes in blade stiffness (weight held constant) associated with change in chord. Table 2. 10 compares section moduli and curvatures for the 1:1 (-6°) and the 1:2 (-8°) blades, which were noted to have similar airload distributions (see 1, above).

TABLE 2. 10

STRUCTURAL COMPARISON OF 1 : 2 PLANFORM WITH EQUIVALENT TWIST BLADE

A/C	M <sub>F</sub>	I crit	I / Ist	Y /Yst	M / Mst
1:1-6°	19939.	5. 80	1. 0	1. 0	1. 0
1 : 2 -8°	22816.	4. 91	. 846	1. 35	1. 145

Observe that stiffness at the critical blade station is 15% less for the 1: 2 planform (-8°) blade. This leads to 35% higher curvature with a resulting 15% higher vibratory bending moment at that blade station.

## E. BLADE MOTIONS

Shown in Figure 7. 58 are typical motions of rigid and articulated blades in high-speed flight. Given are results for the Hl and Hl-R rotor systems at 150 knots. Deflection curves for the -8 degree twist, 1:1 planform blades, rigid and articulated, are plotted at 60-degree azimuth intervals. Curves shown represent variations about blade steady displacements, which are plotted for each aircraft in Figure 7. 59. Similarity of steady blade responses is due to the selected value for the rigid-rotor precone angle. This was based on the steady response of the articulated blade.

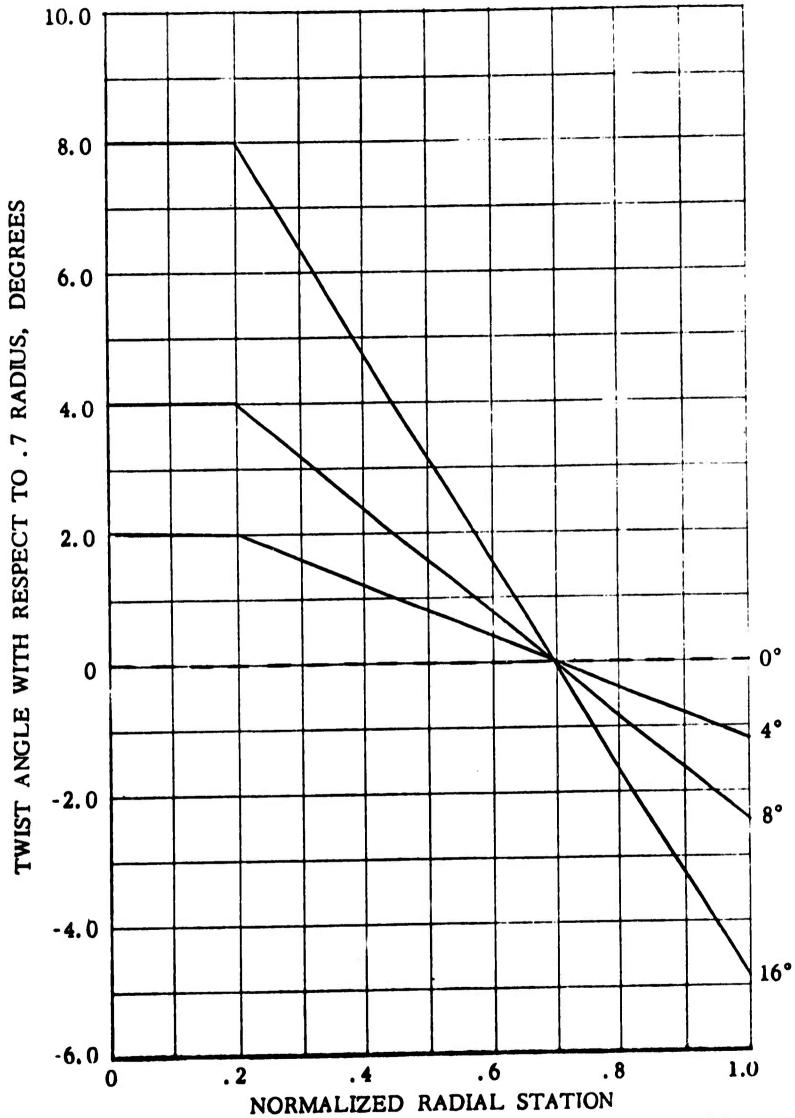


FIG. 7.1 RADIAL DISTRIBUTION OF BLADE TWIST

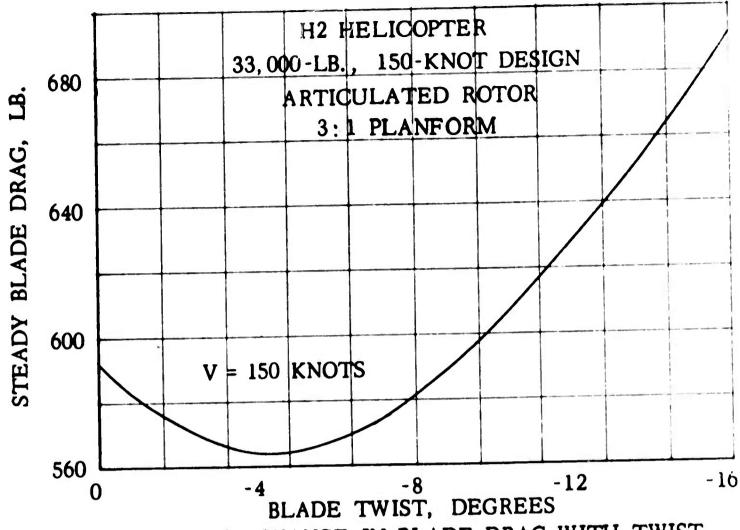


FIG. 7.3 CHANGE IN BLADE DRAG WITH TWIST

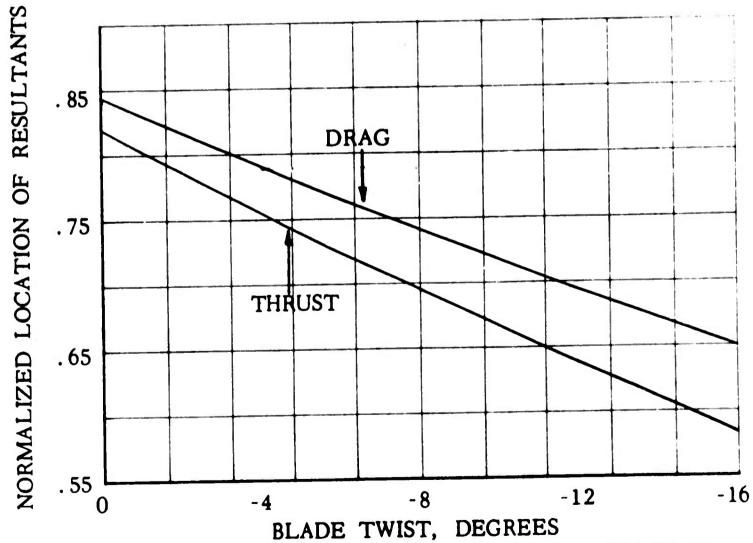


FIG. 7.4 CHANGE IN LOCATION OF RESULTANT DRAG AND THRUST WITH TWIST

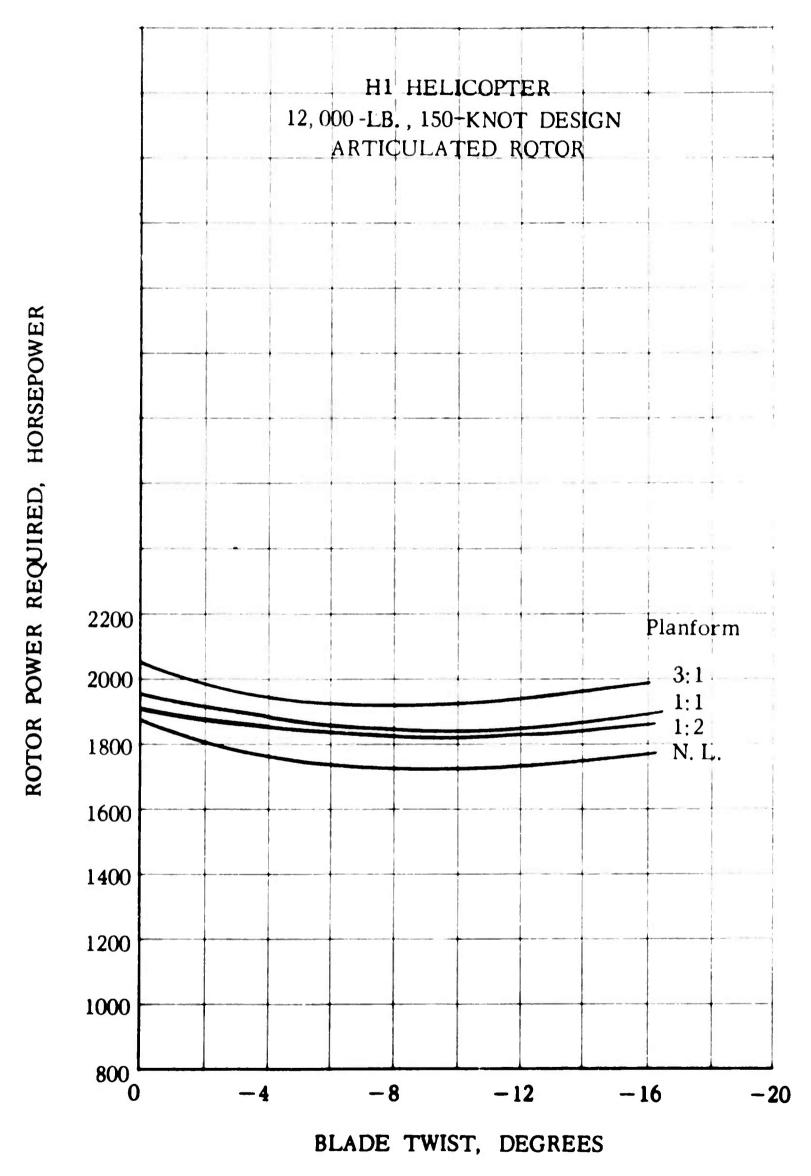


FIG. 7.5 CHANGE IN POWER WITH BLADE TWIST

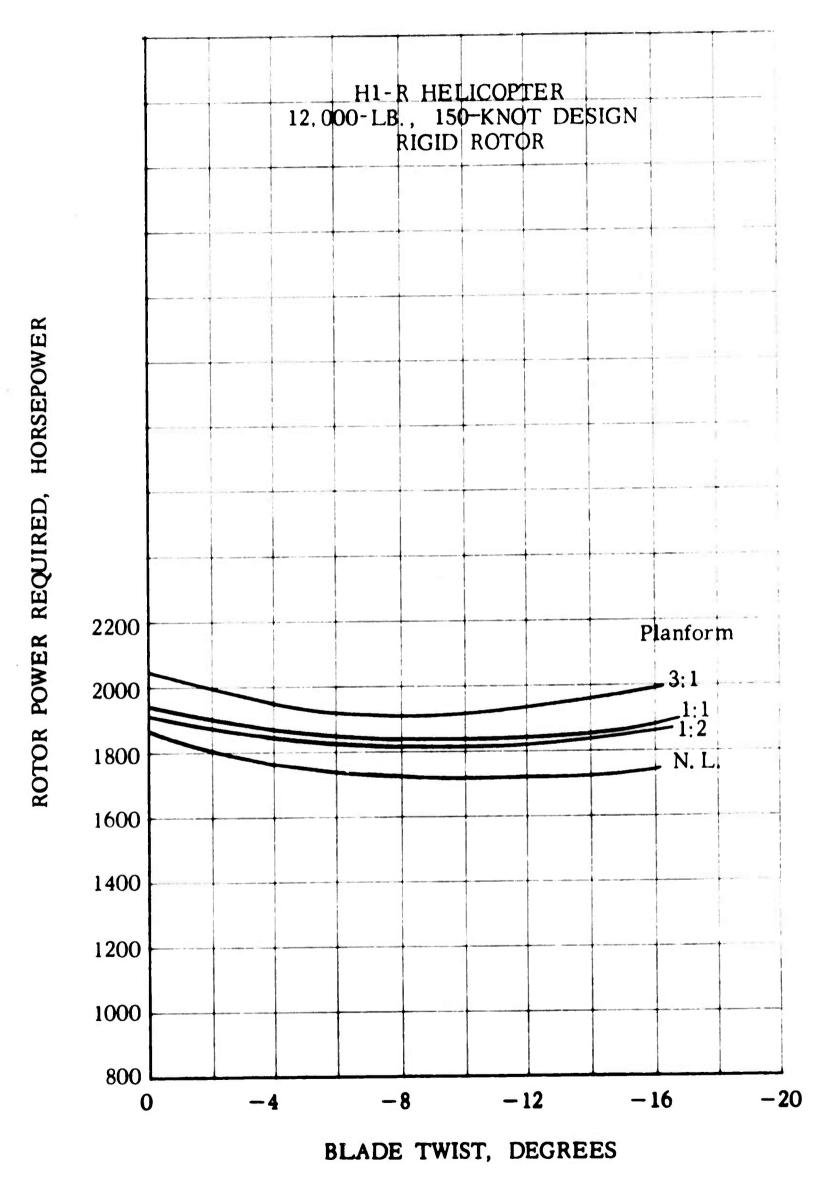


FIG. 7.6 CHANGE IN POWER WITH BLADE TWIST

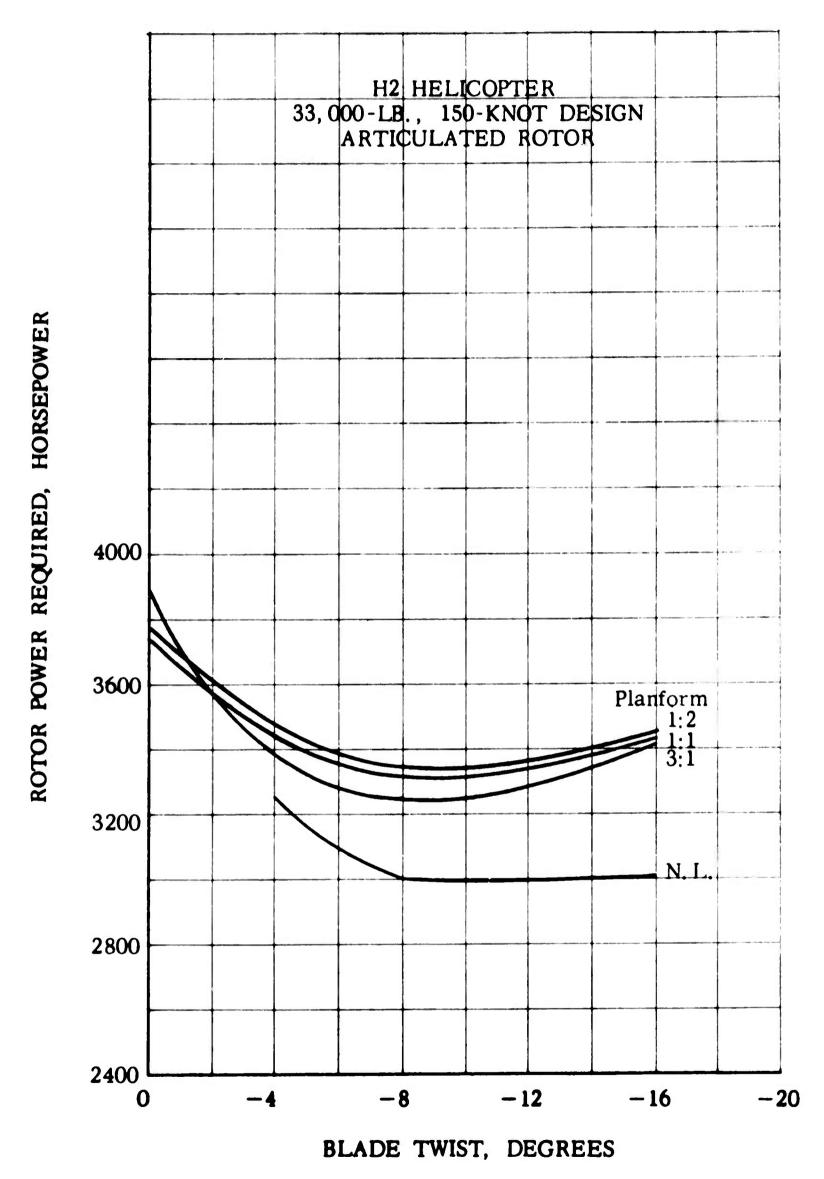


FIG. 7.7 CHANGE IN POWER WITH BLADE TWIST

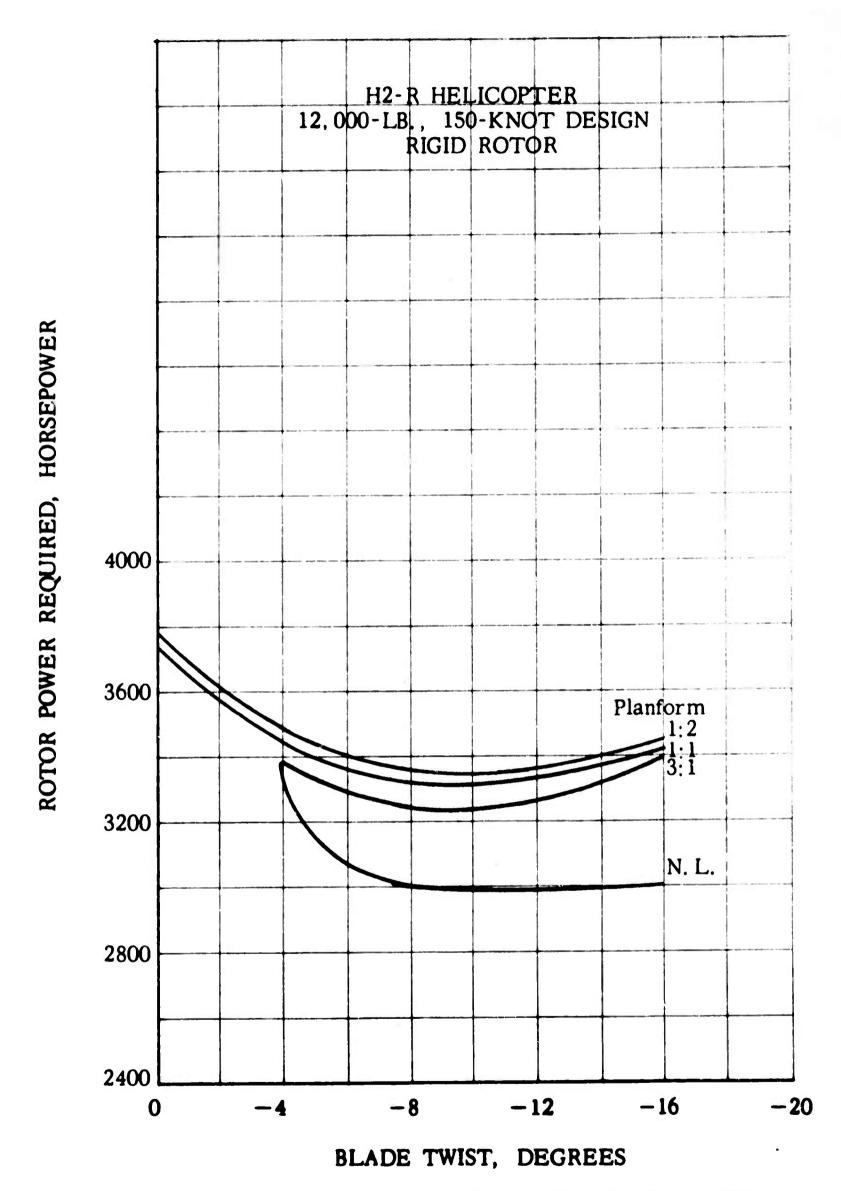


FIG. 7.8 CHANGE IN POWER WITH BLADE TWIST

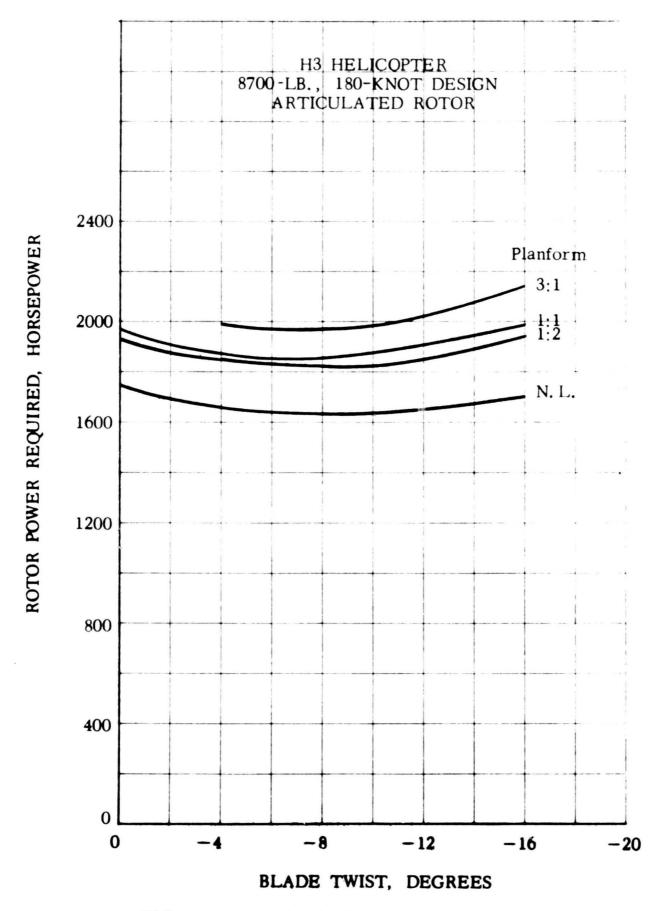


FIG. 7.9 CHANGE IN POWER WITH BLADE TWIST

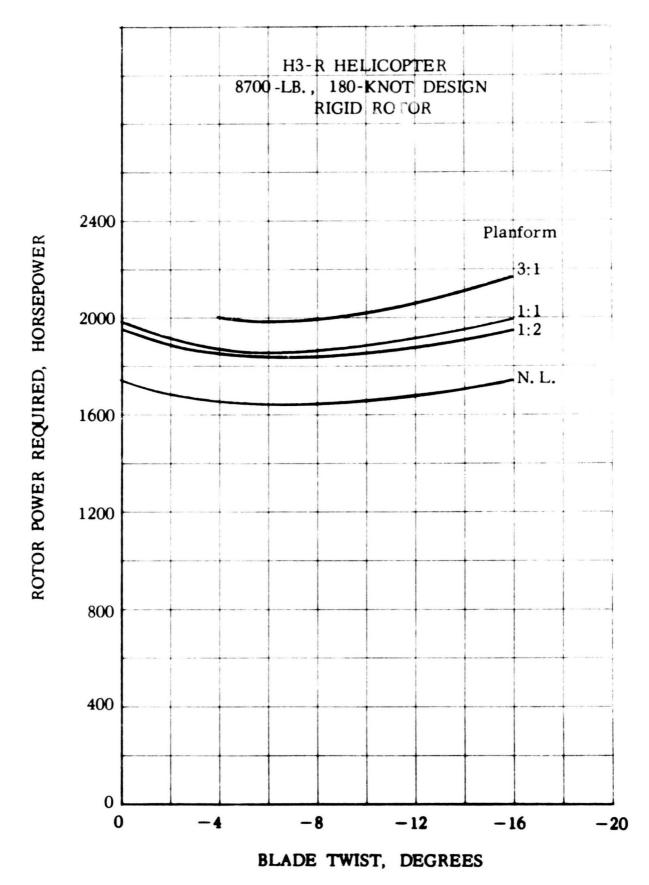


FIG.7.10 CHANGE IN POWER WITH BLADE TWIST

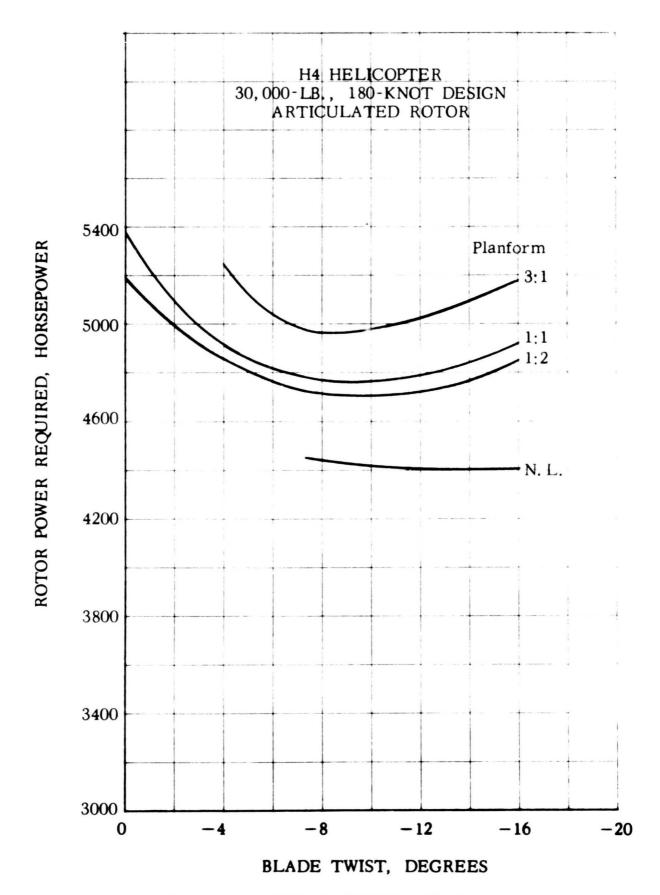


FIG. 7.11 CHANGE IN POWER WITH BLADE TWIST

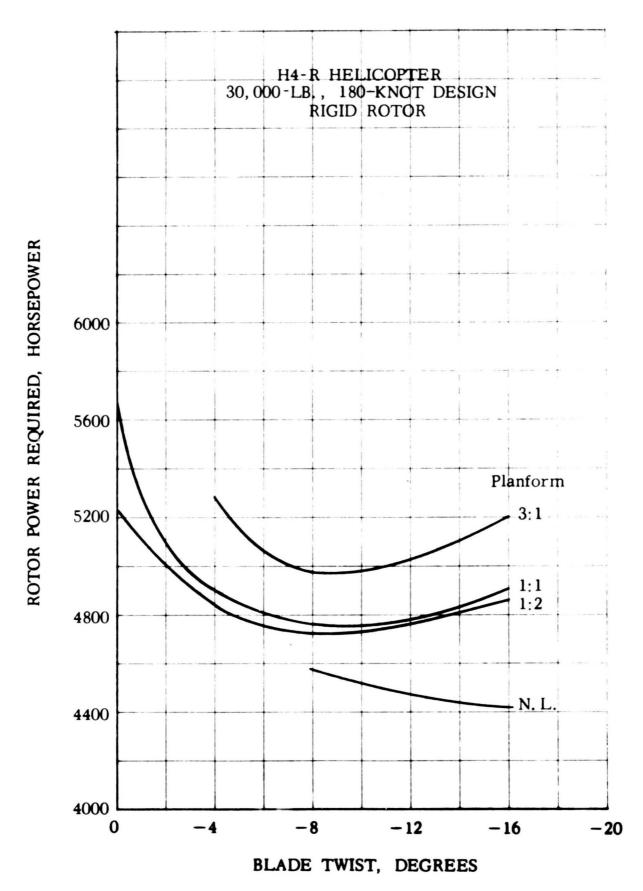


FIG. 7-12 CHANGE IN POWER WITH BLADE TWIST

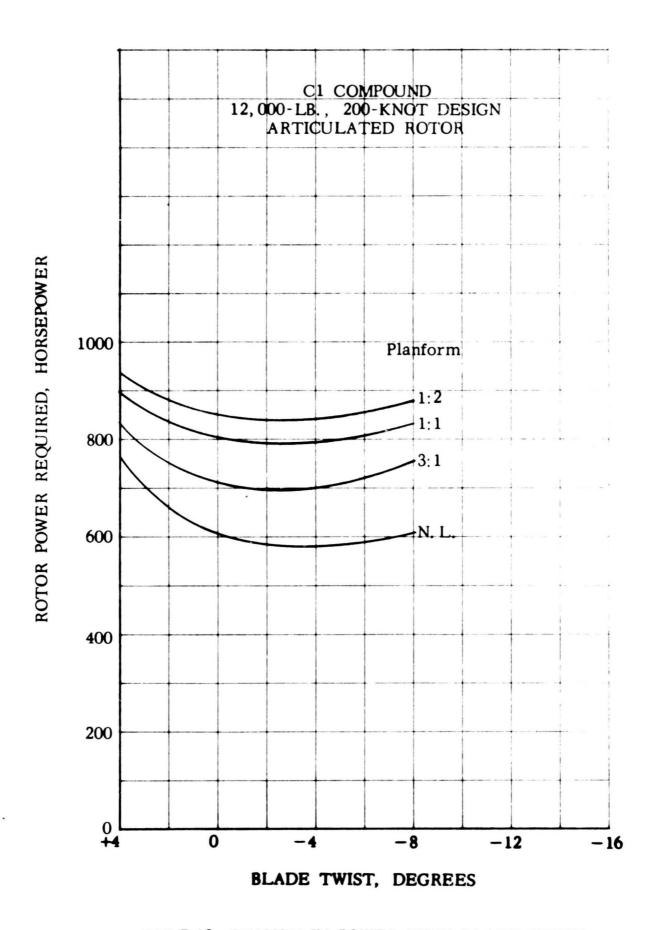


FIG. 7.13 CHANGE IN POWER WITH BLADE TWIST

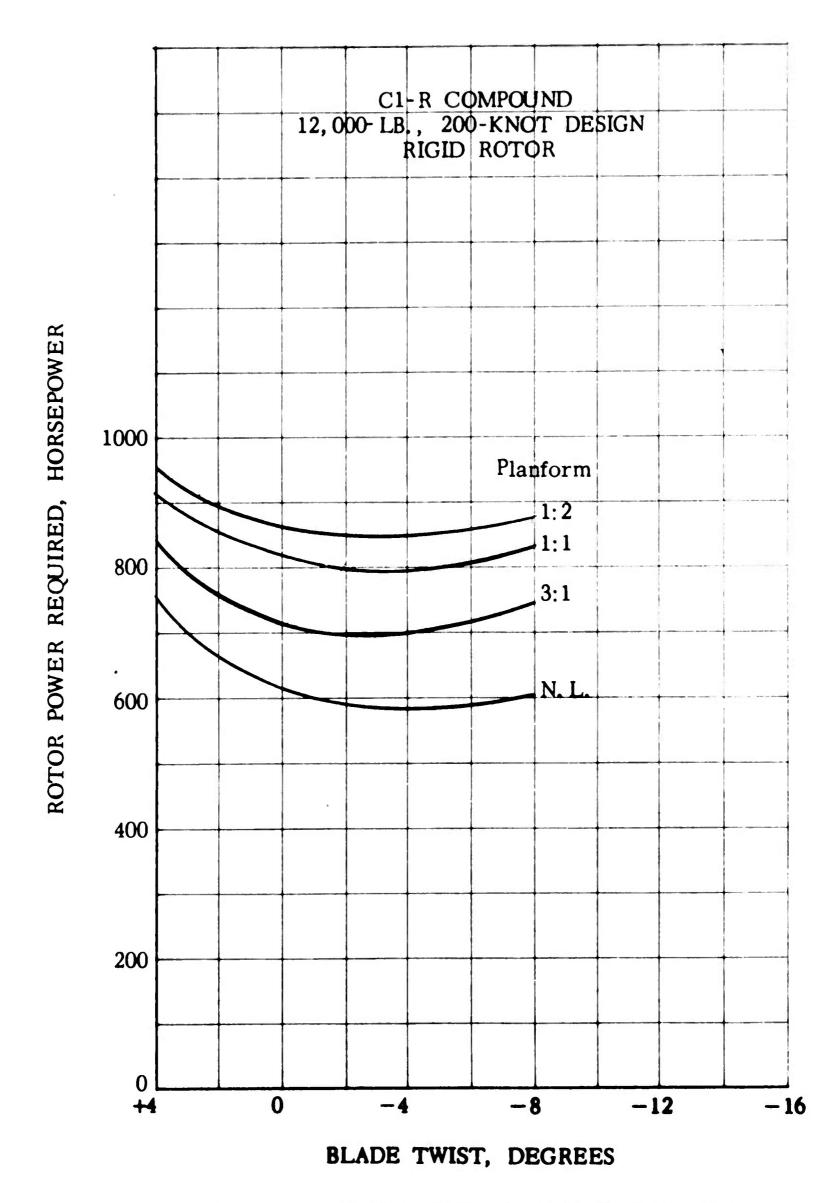


FIG.7.14 CHANGE IN POWER WITH BLADE TWIST

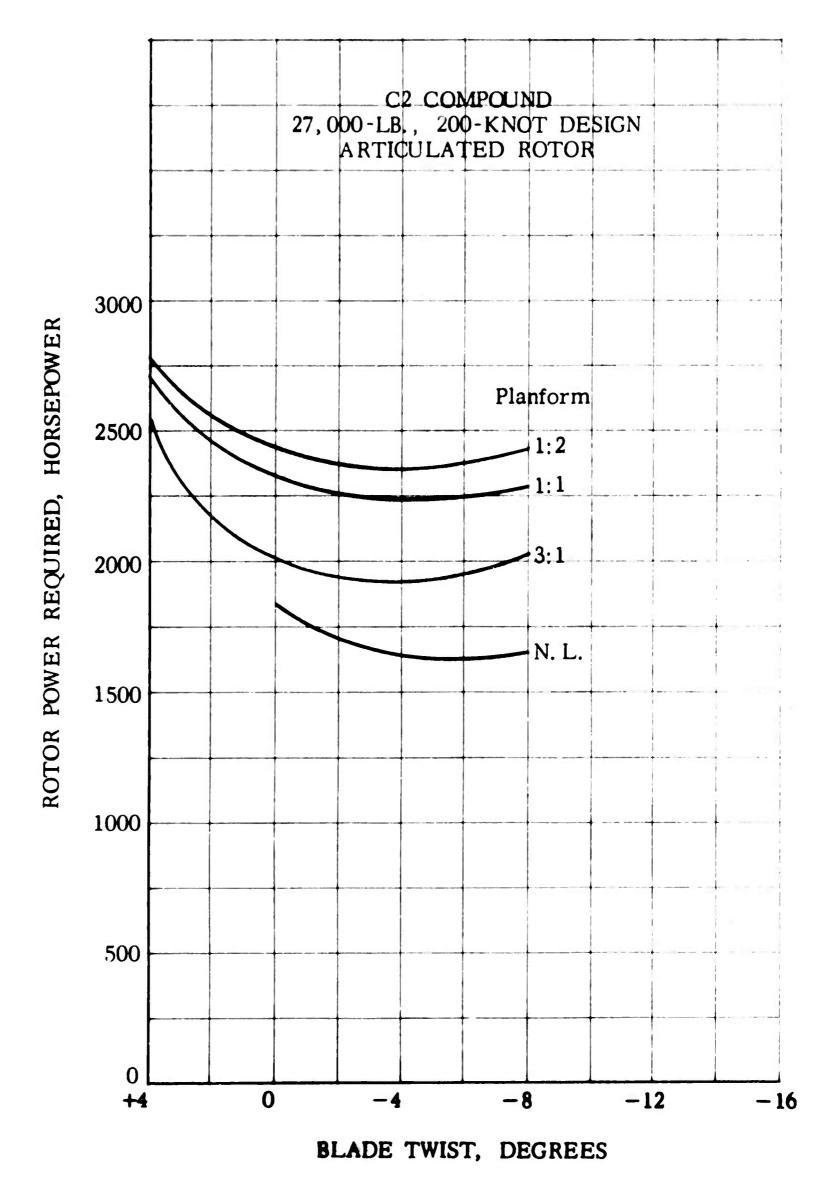


FIG. 7.15 CHANGE IN POWER WITH BLADE TWIST

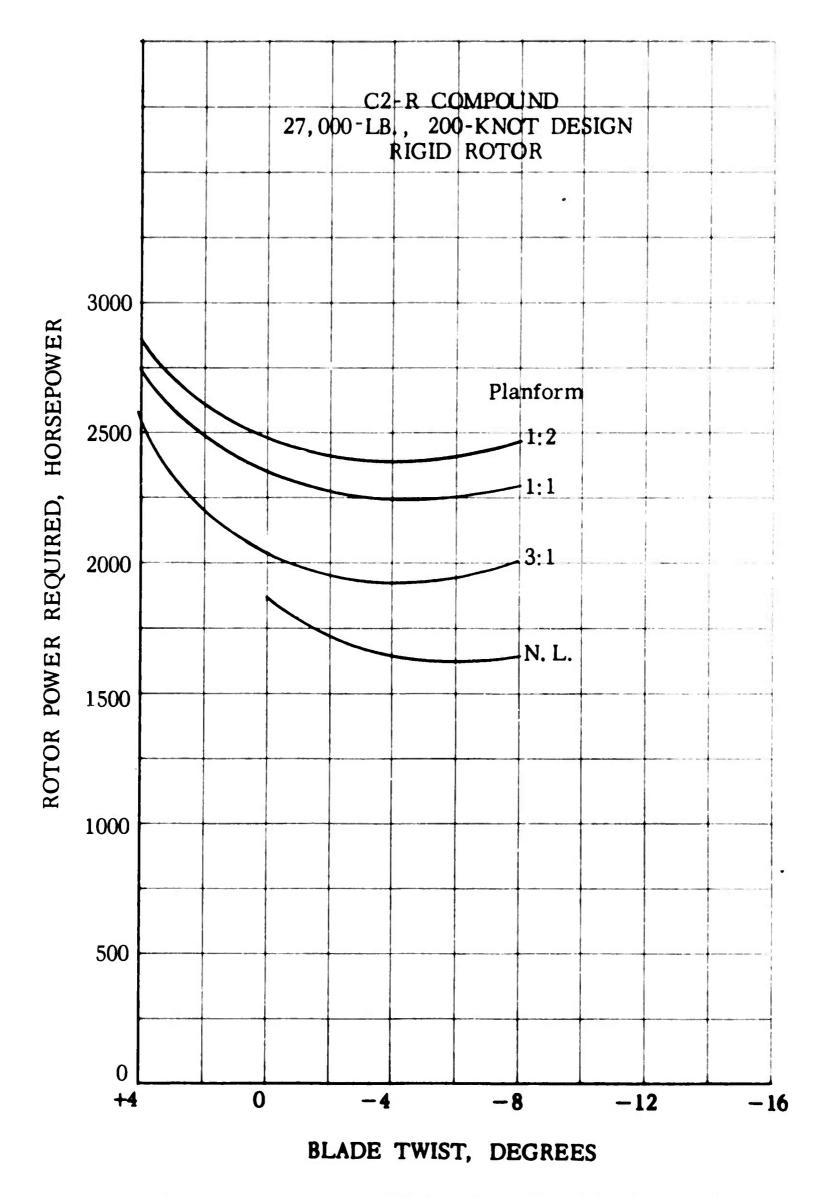


FIG. 7.16 CHANGE IN POWER WITH BLADE TWIST

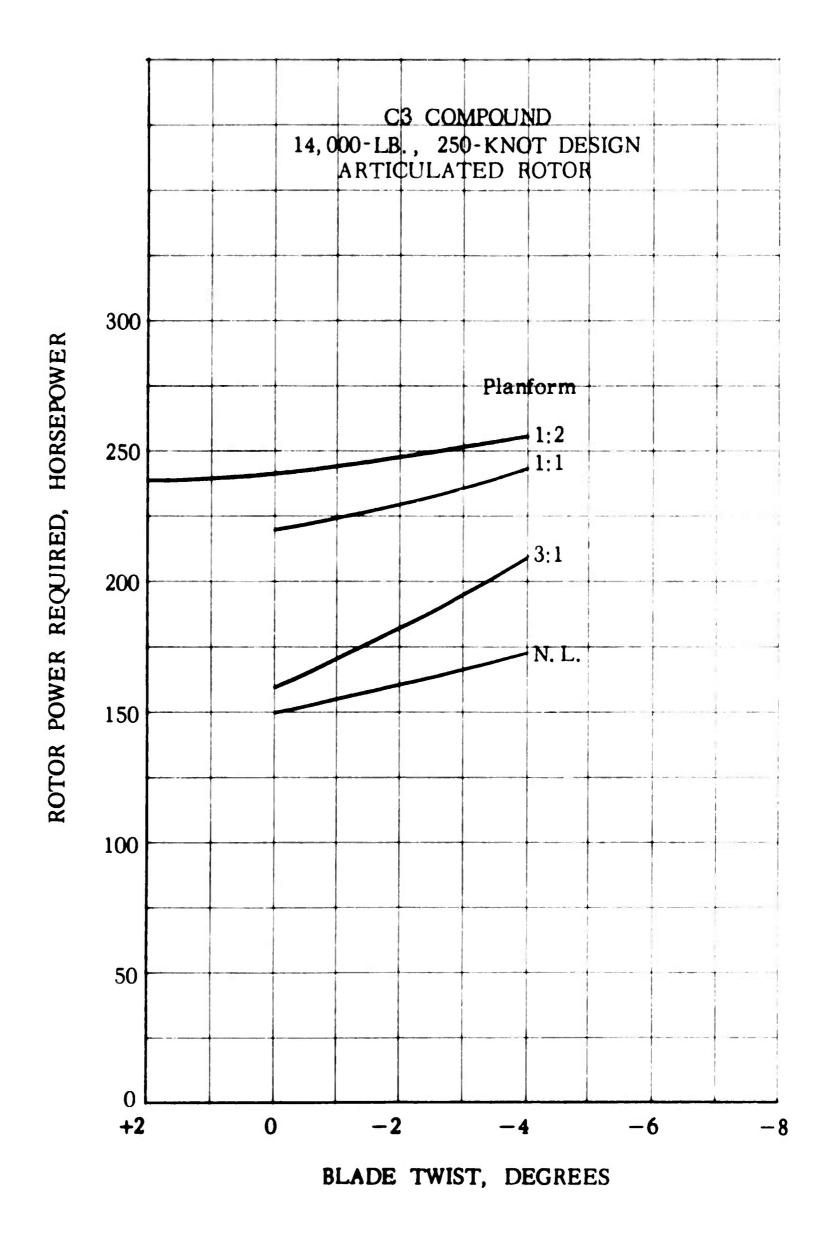


FIG. 7.17 CHANGE IN POWER WITH BLADE TWIST

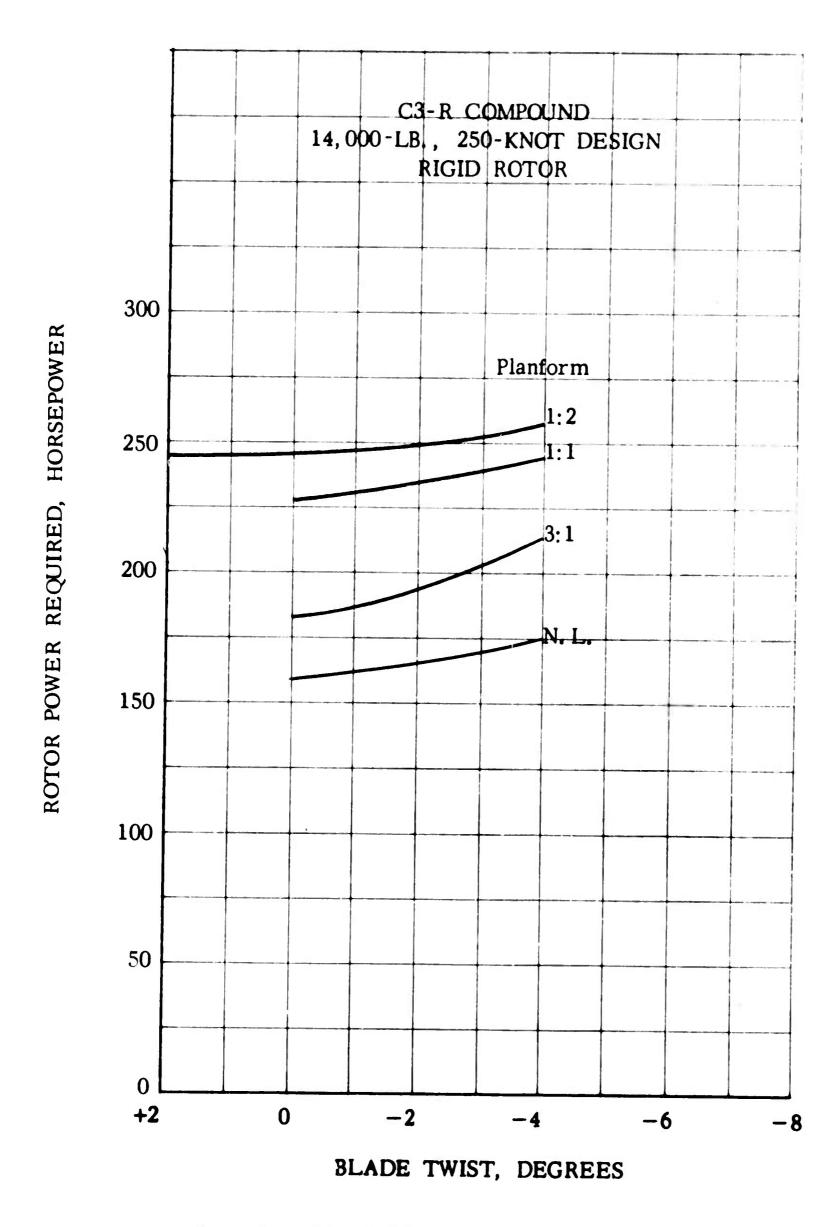


FIG. 7.18 CHANGE IN POWER WITH BLADE TWIST 87

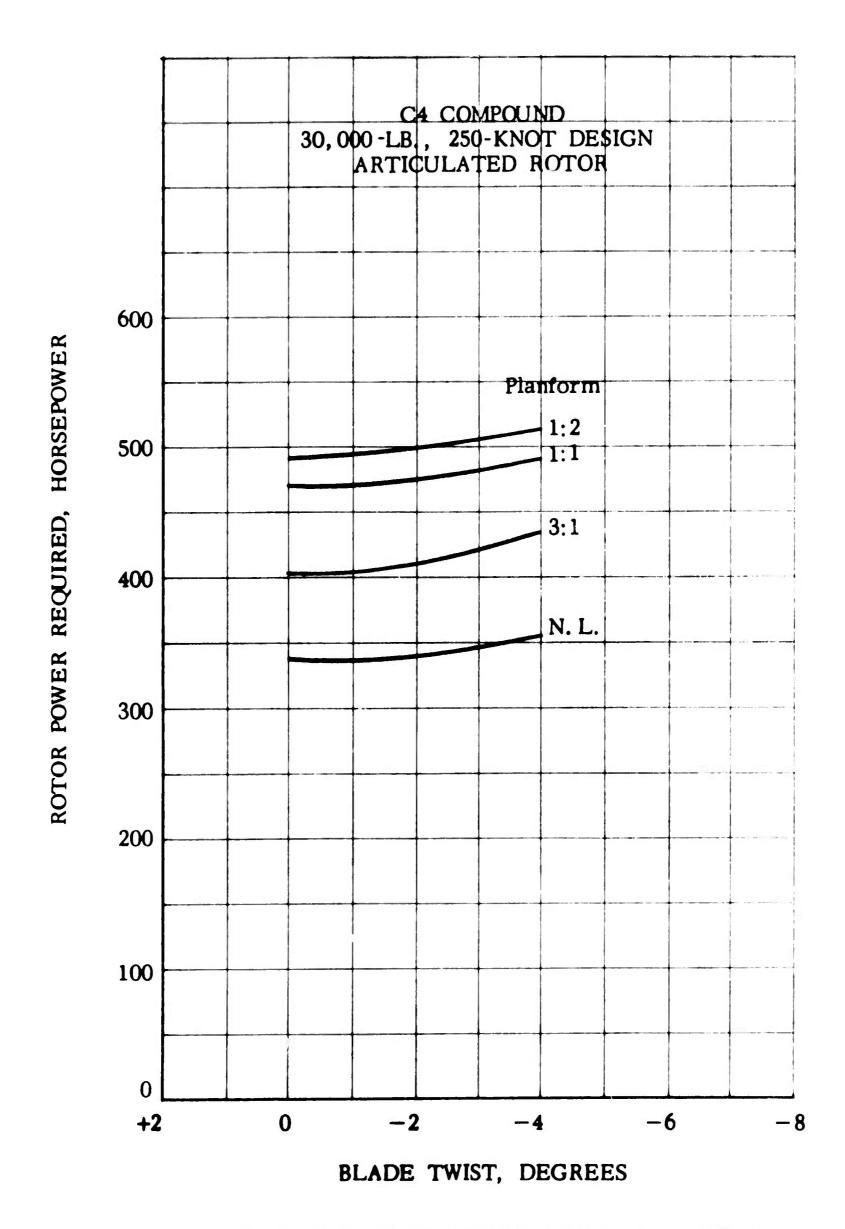


FIG. 7.19 CHANGE IN POWER WITH BLADE TWIST

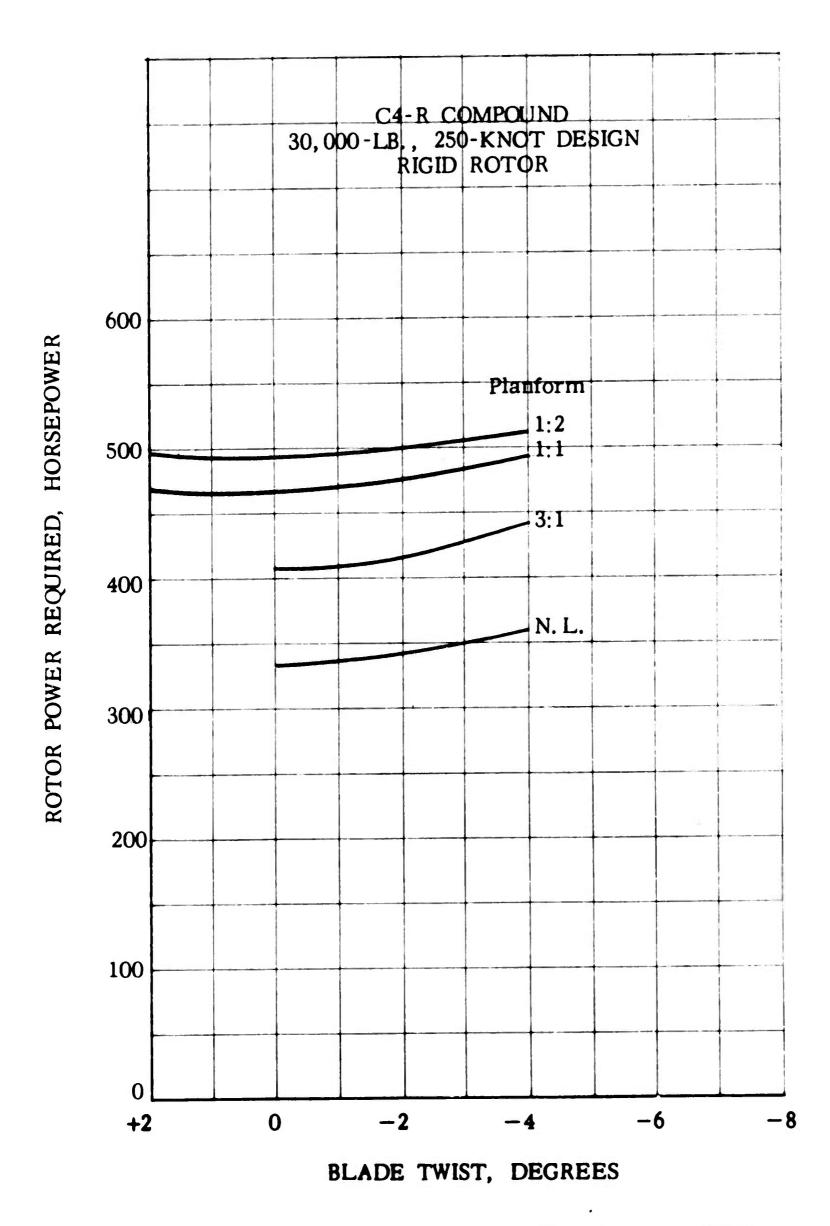


FIG. 7.20 CHANGE IN POWER WITH BLADE TWIST 89

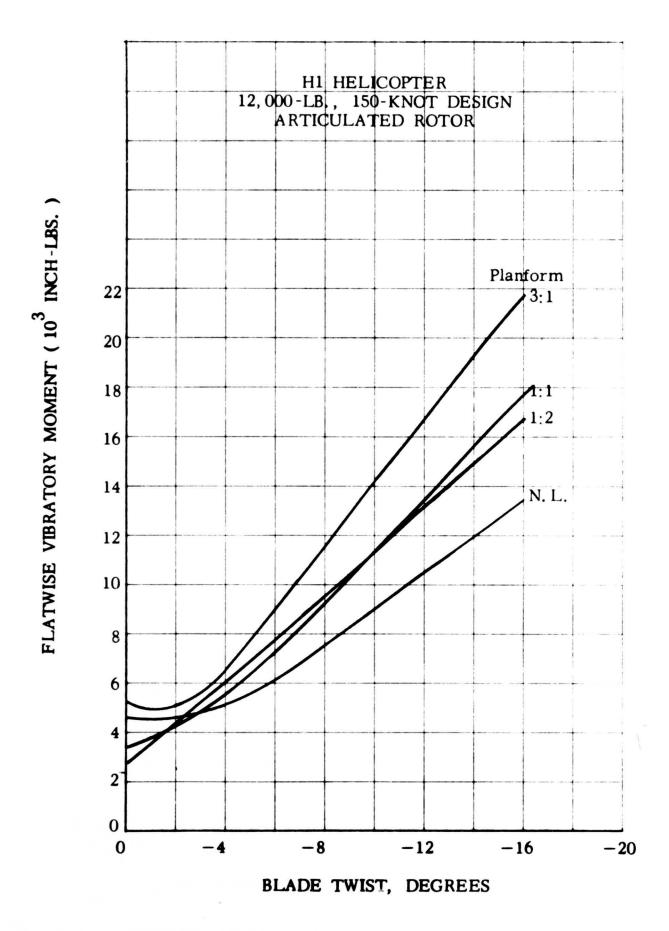


FIG. 7.21 EFFECT OF TWIST ON FLATWISE MOMENT

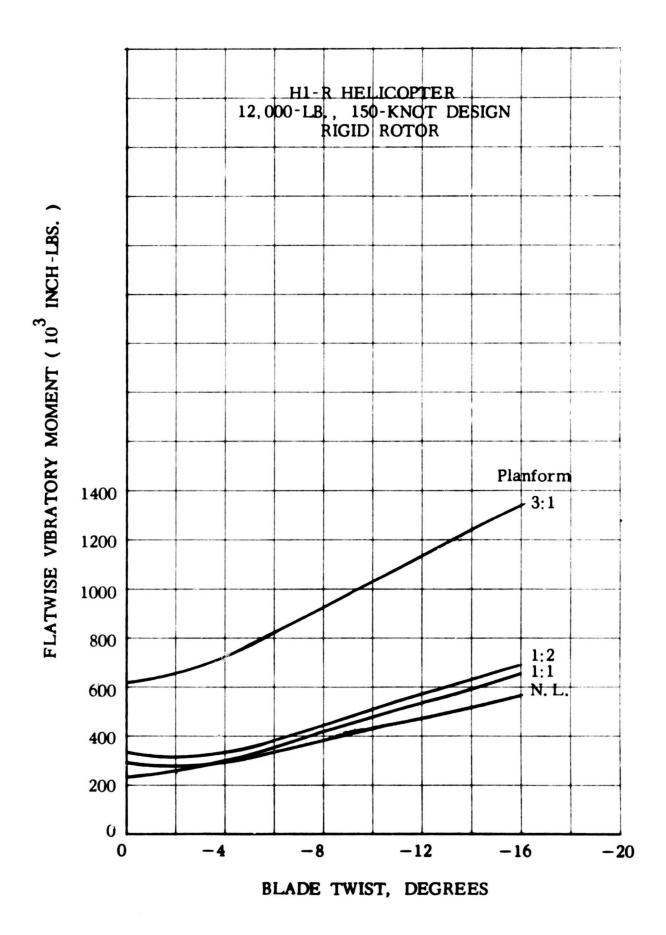


FIG. 7.22 EFFECT OF TWIST ON FLATWISE MOMENT

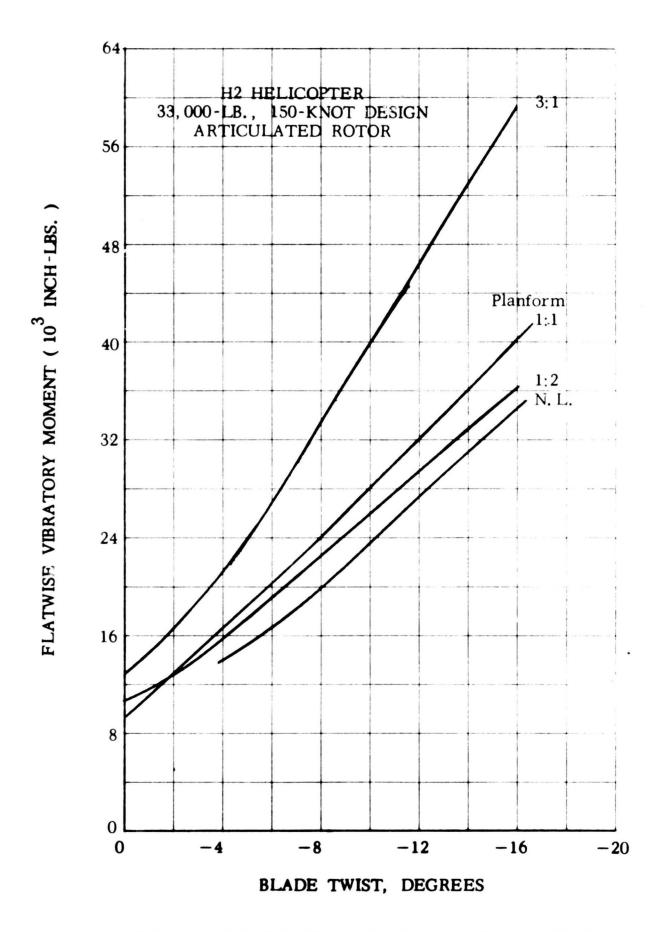


FIG. 7.23 EFFECT OF TWIST ON FLATWISE MOMENT

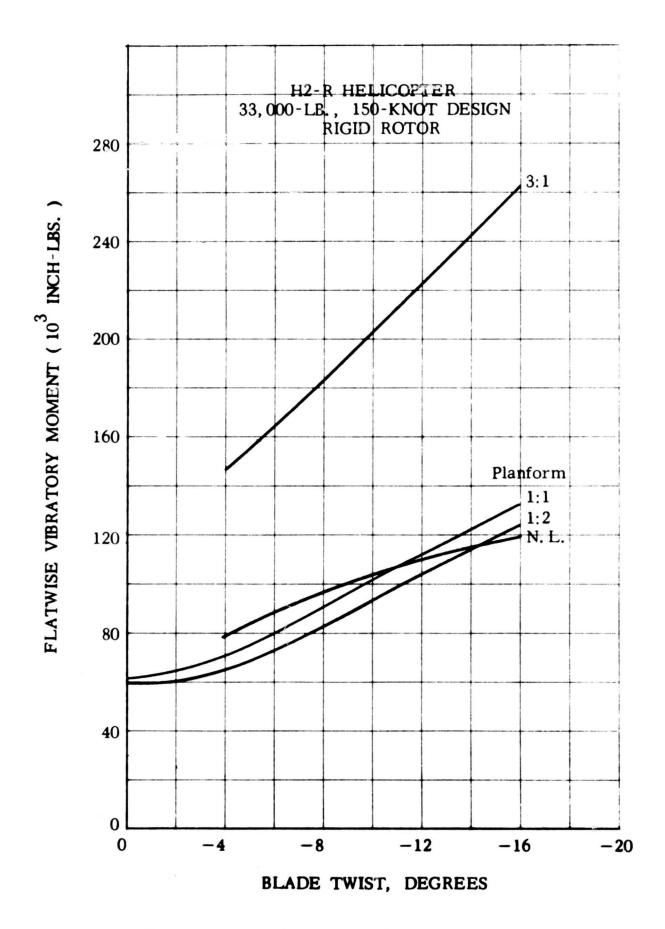


FIG. 7.24 EFFECT OF TWIST ON FLATWISE MOMENT

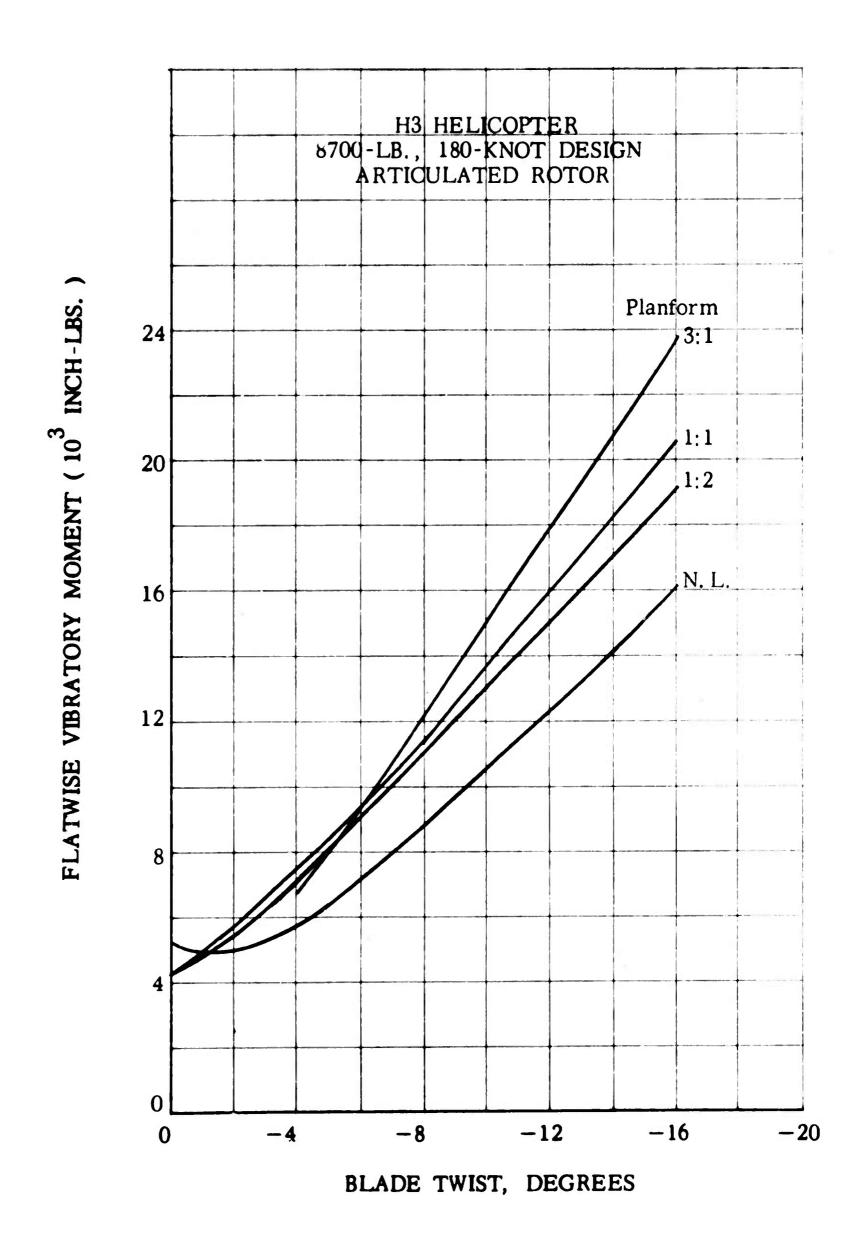


FIG. 7.25 EFFECT OF TWIST ON FLATWISE MOMENT
94

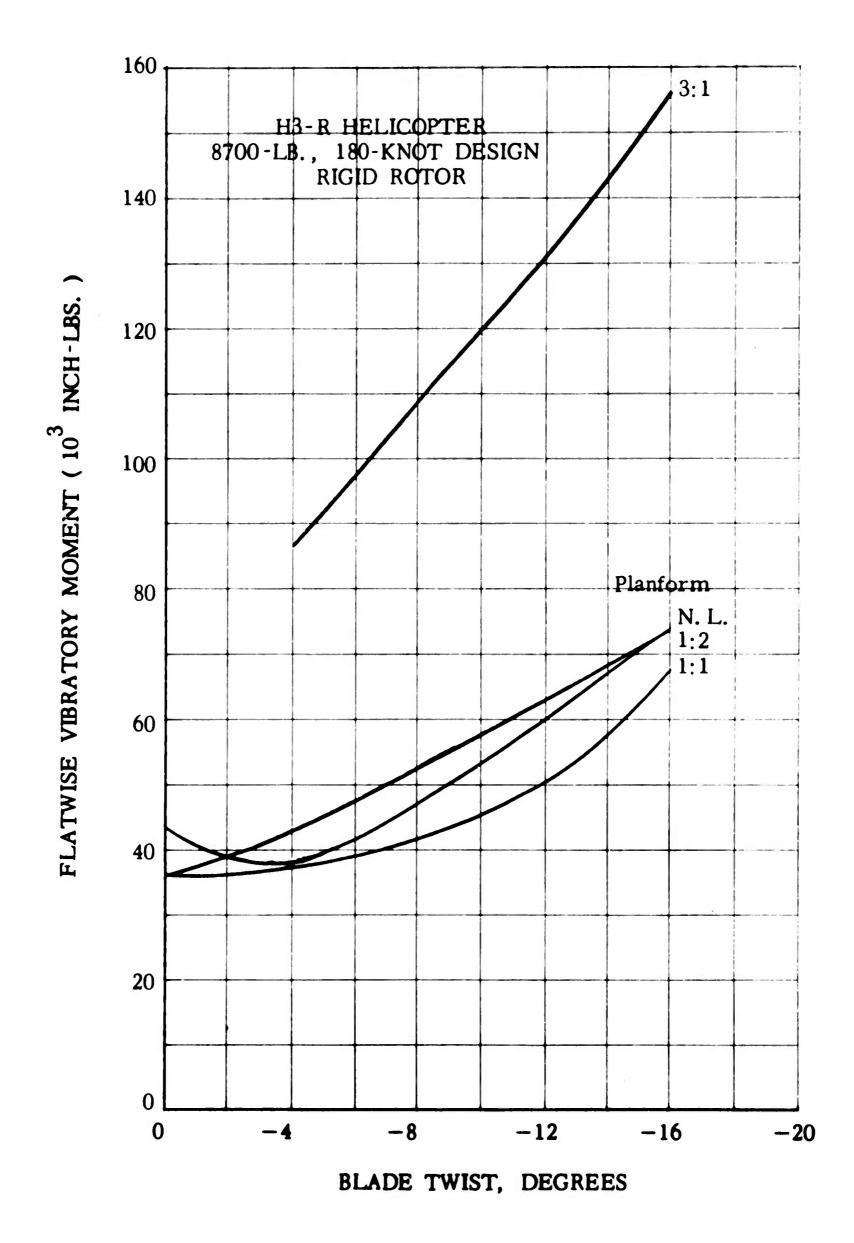


FIG. 7.26 EFFECT OF TWIST ON FLATWISE MOMENT

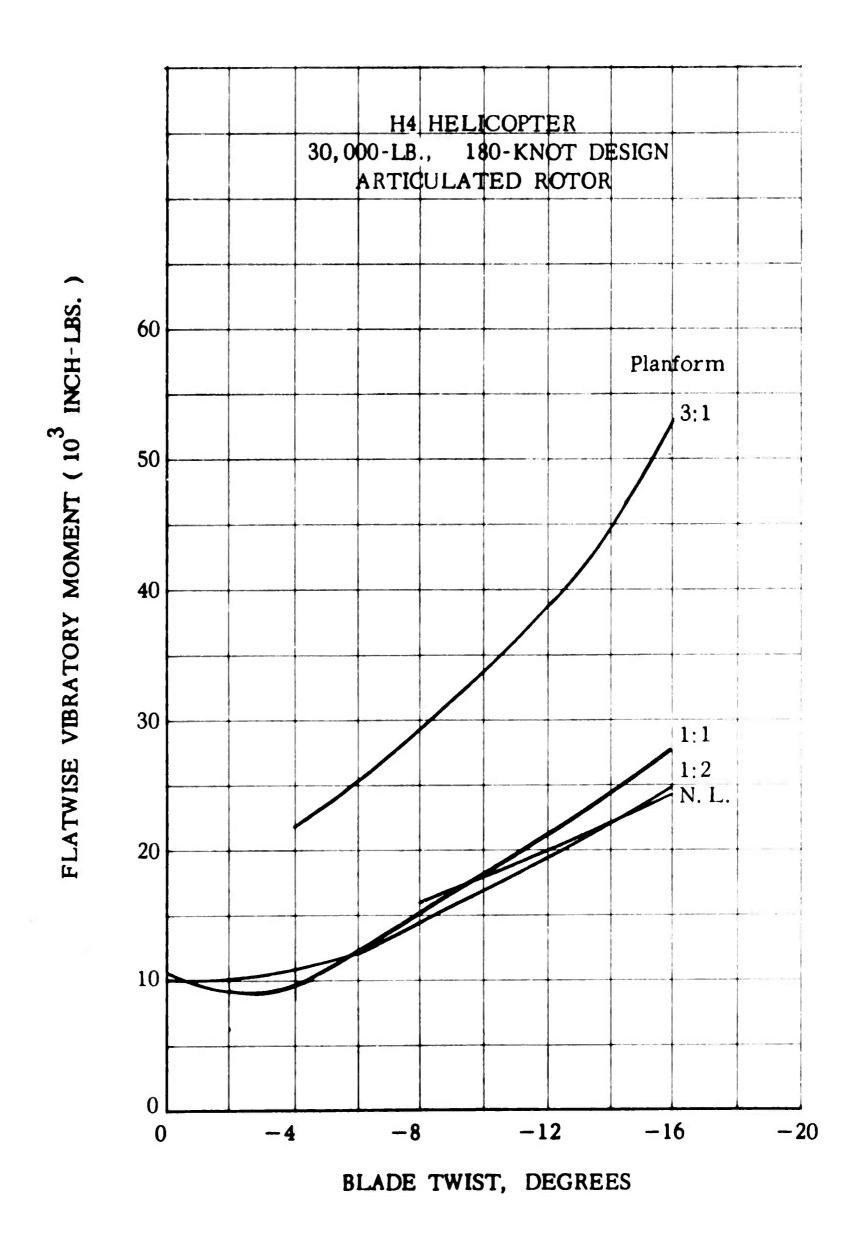


FIG. 7.27 EFFECT OF TWIST ON FLATWISE MOMENT 96

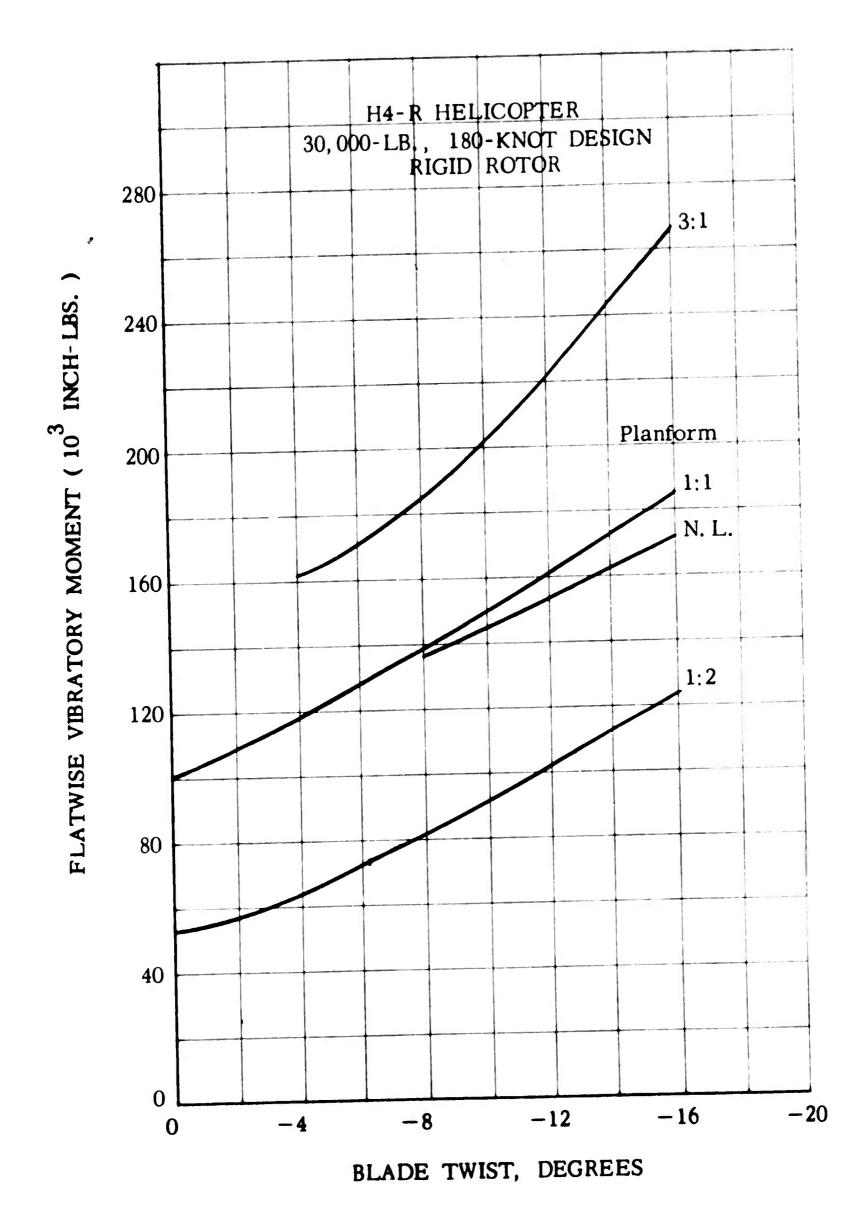


FIG. 7.28 EFFECT OF TWIST ON FLATWISE MOMENT
97

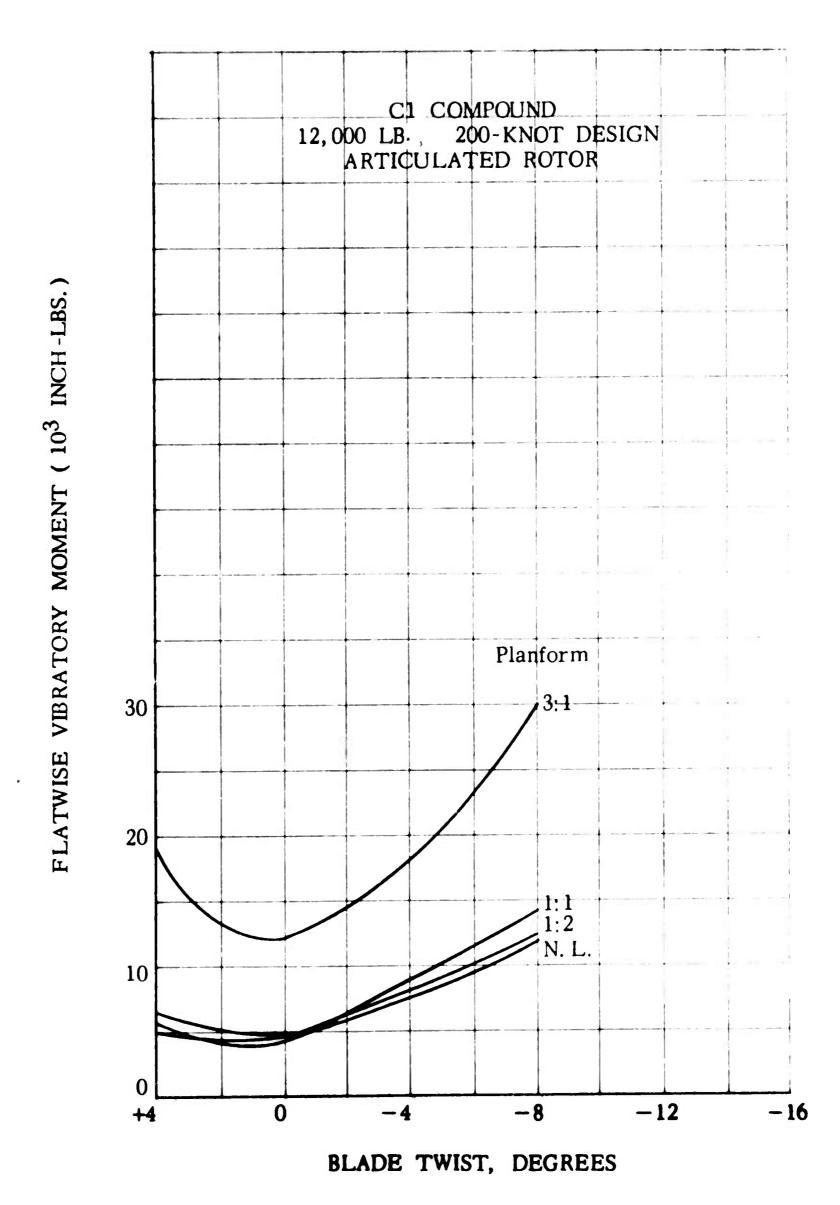


FIG. 7.29 EFFECT OF TWIST ON FLATWISE MOMENT
98

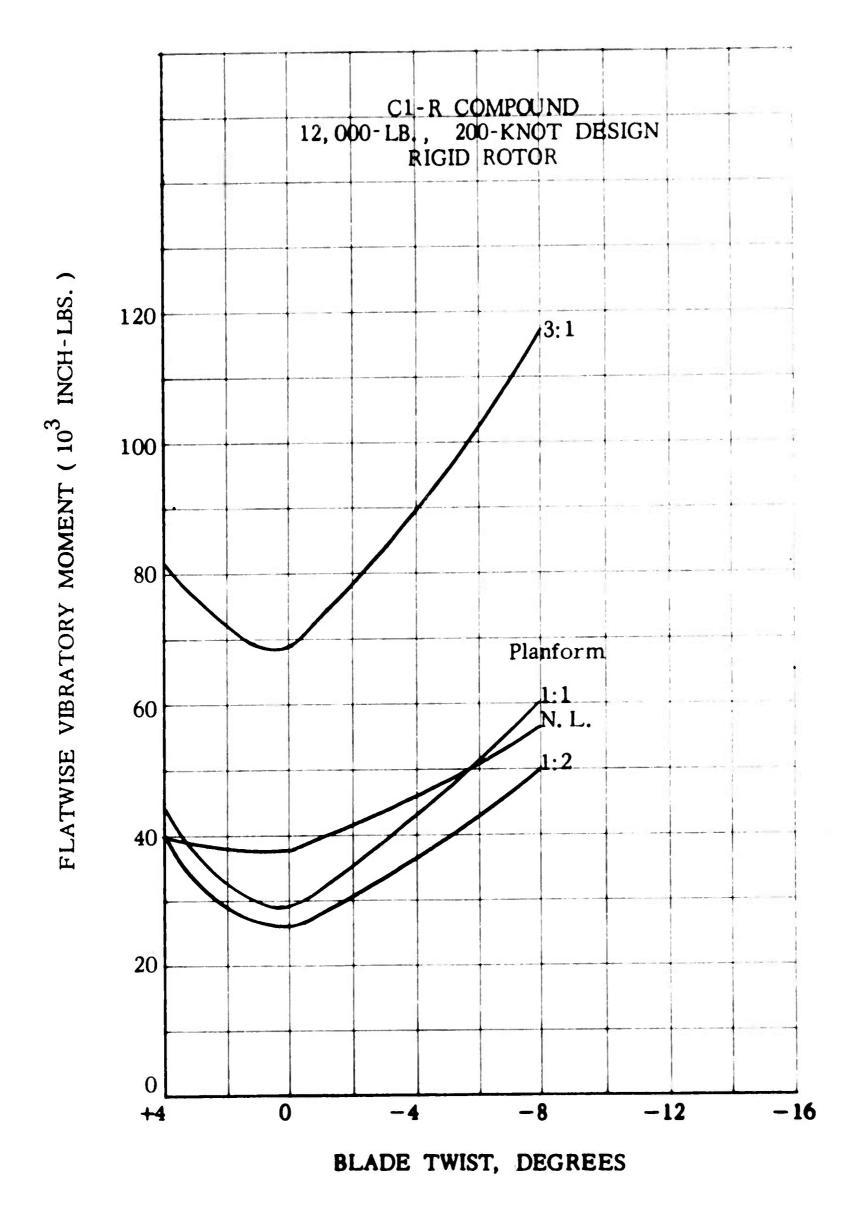


FIG. 7.30 EFFECT OF TWIST ON FLATWISE MOMENT
99

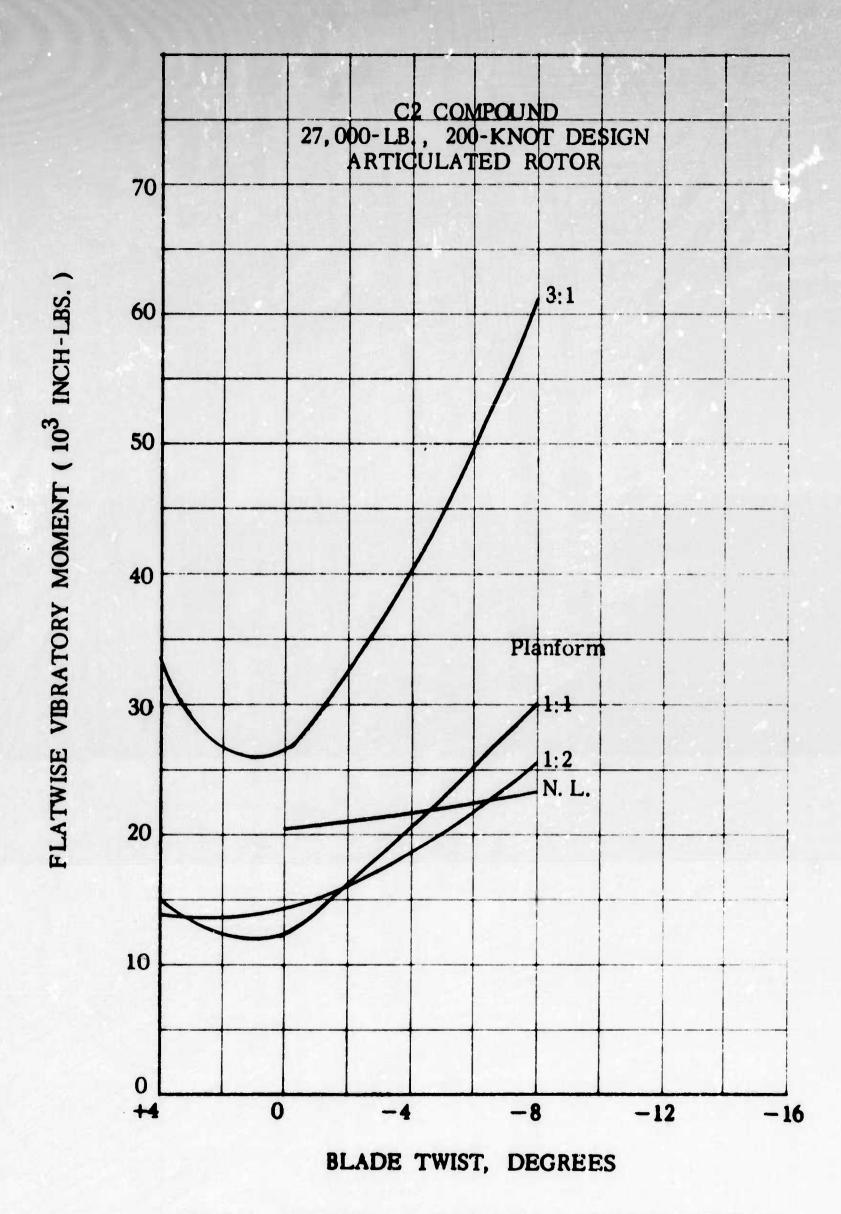


FIG.7.31 EFFECT OF TWIST ON FLATWISE MOMENT 100

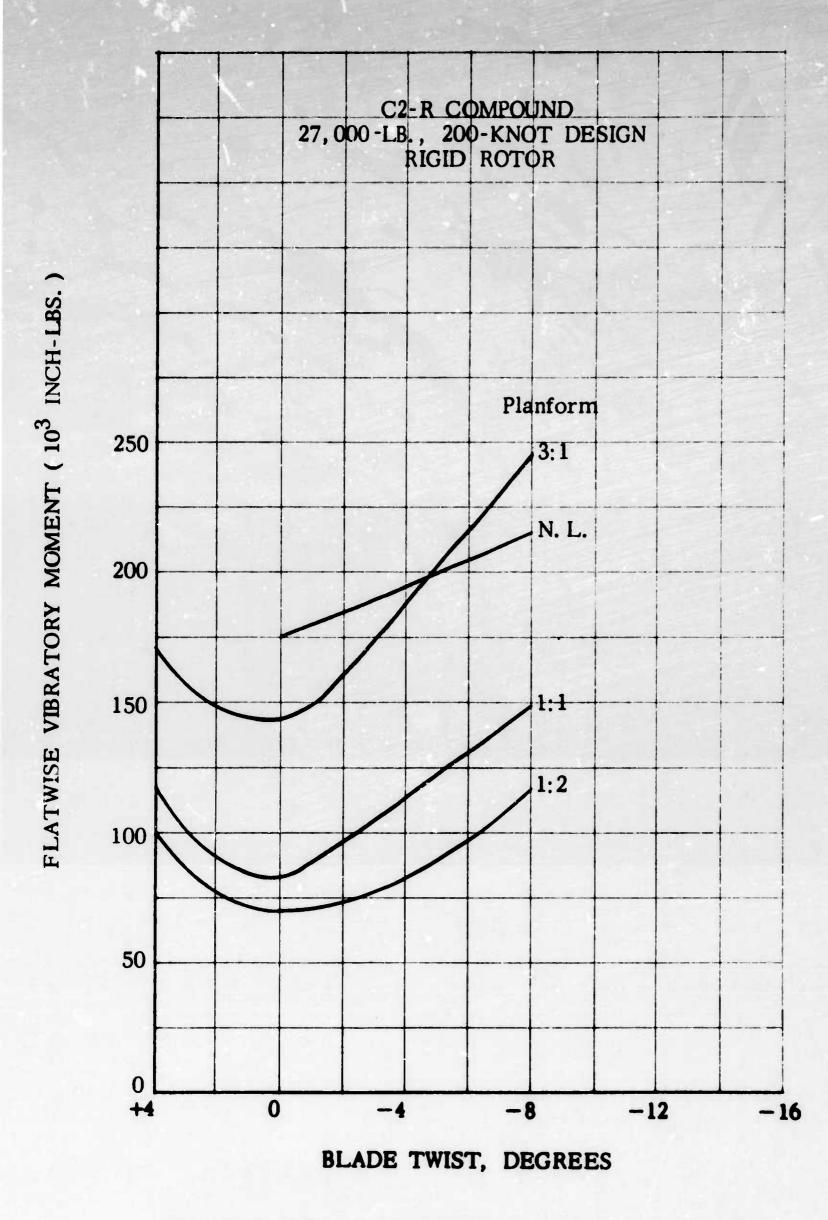


FIG. 7.32 EFFECT OF TWIST ON FLATWISE MOMENT 101

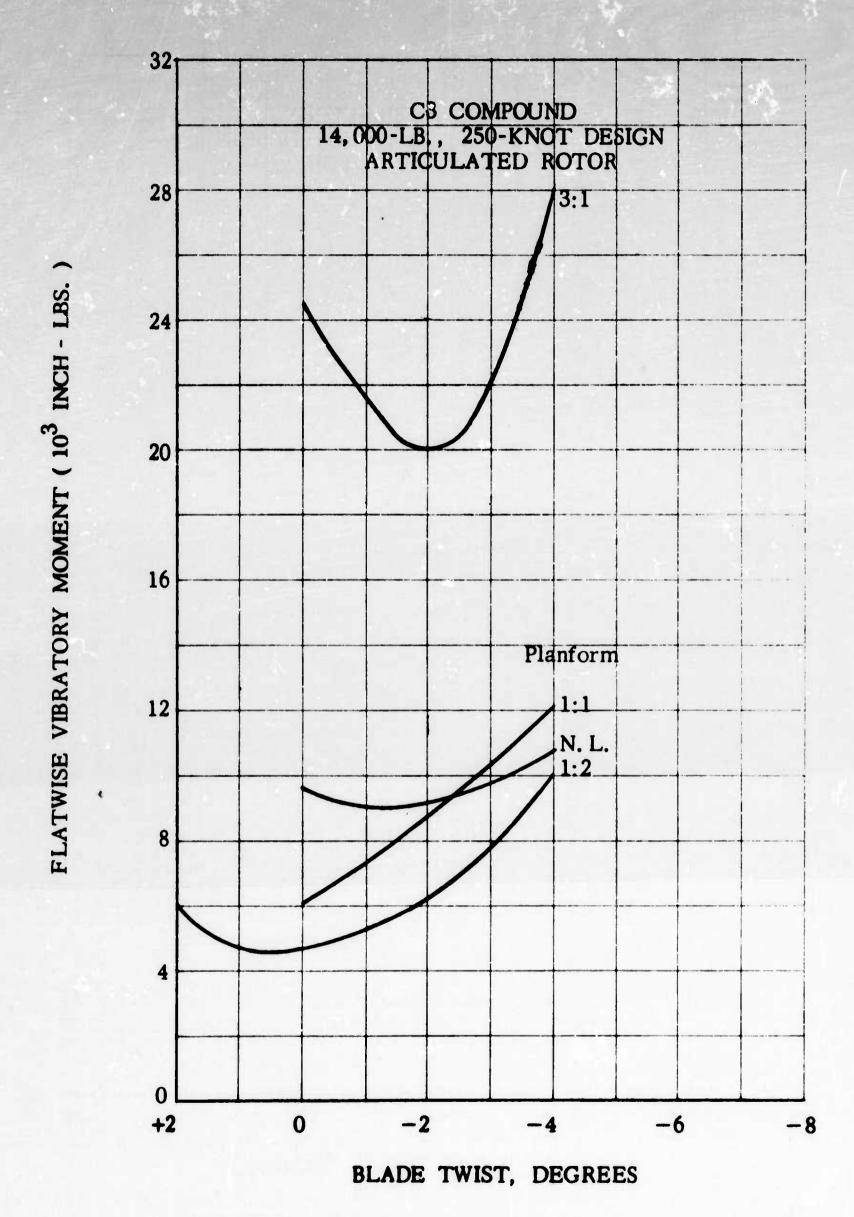


FIG. 7.33 EFFECT OF TWIST ON FLATWISE MOMENT
102

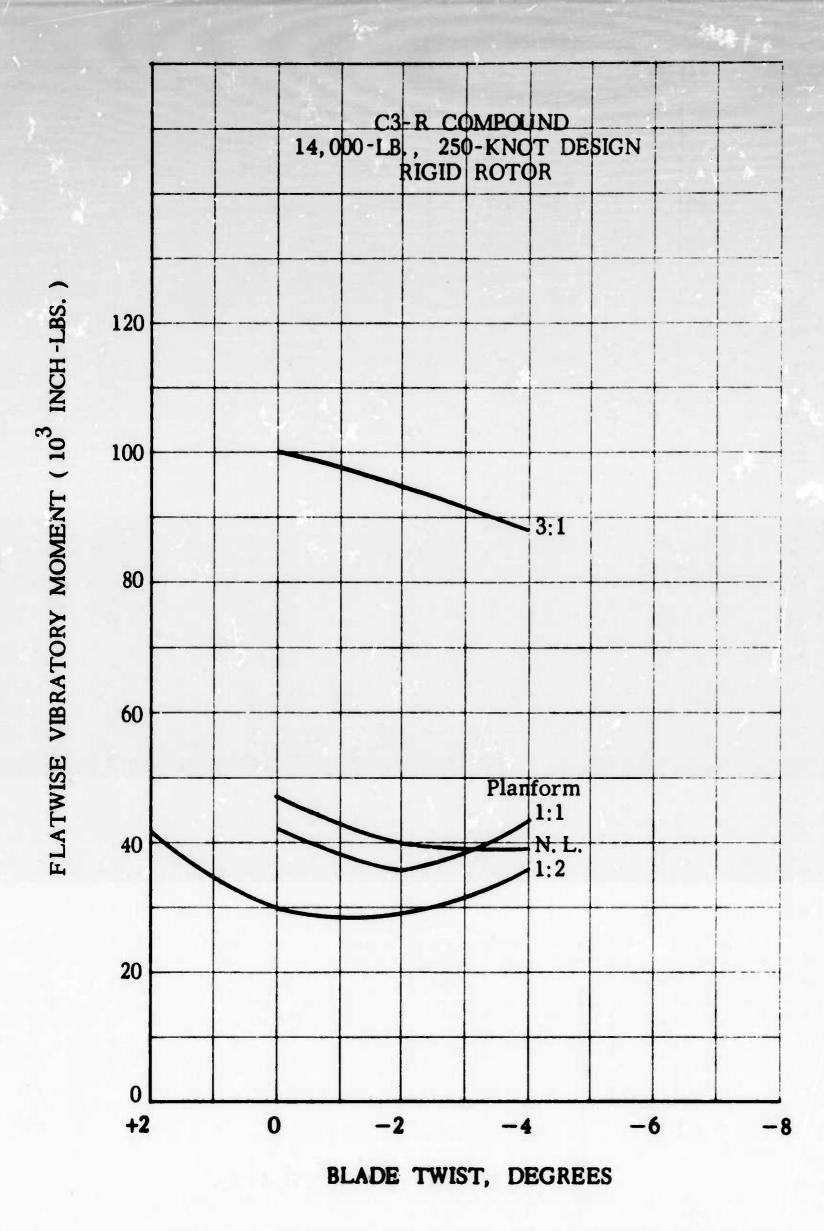


FIG. 7.34 EFFECT OF TWIST ON FLATWISE MOMENT 103

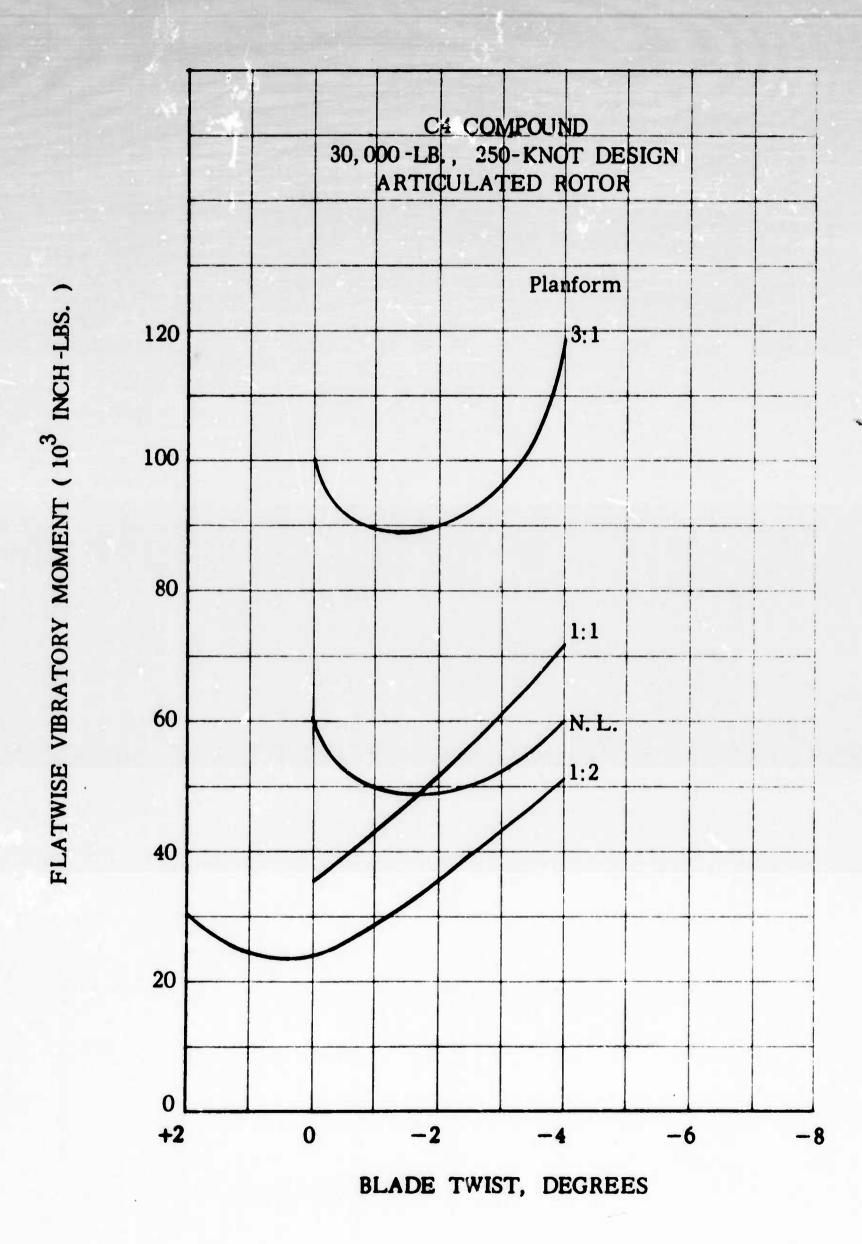


FIG. 7.35 EFFECT OF TWIST ON FLATWISE MOMENT 104

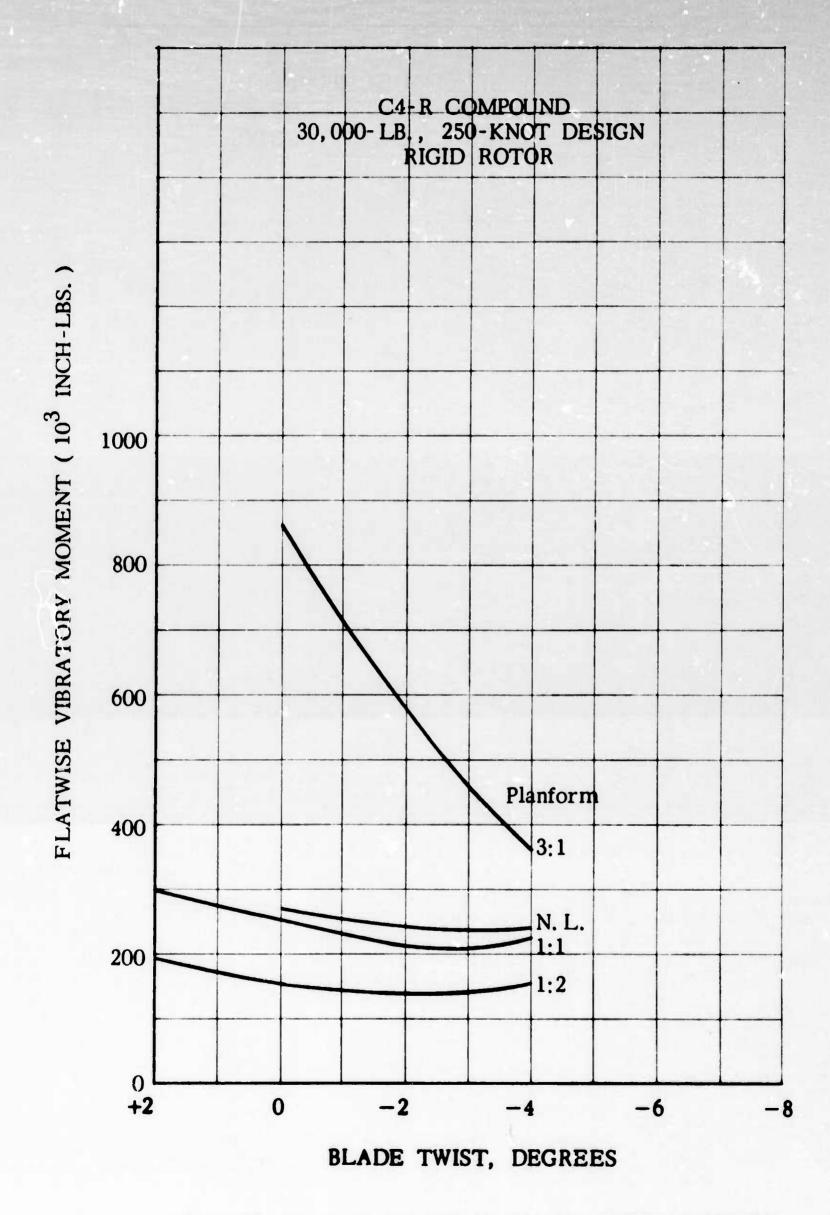
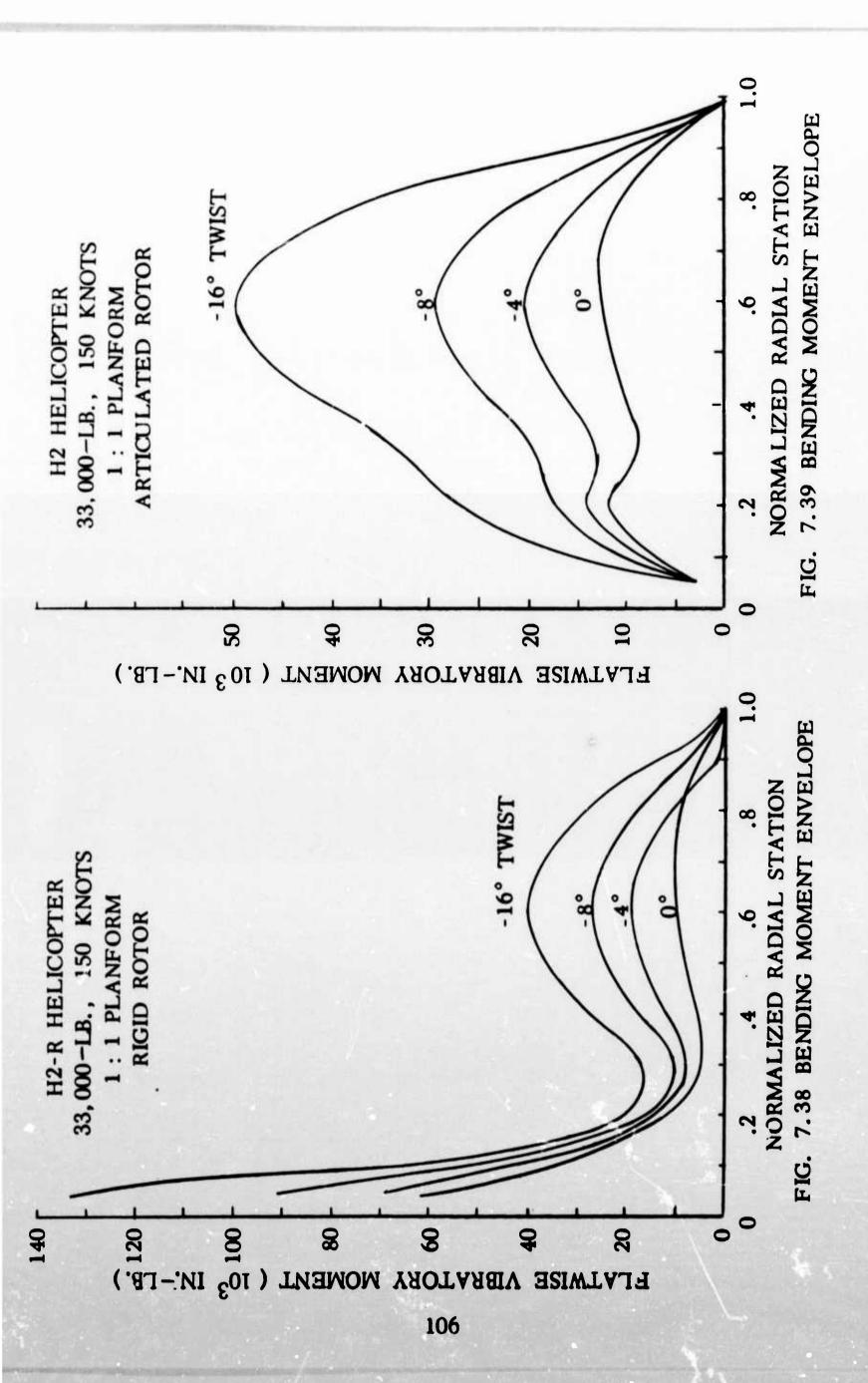


FIG. 7.36 EFFECT OF TWIST ON FLATWISE MOMENT 105



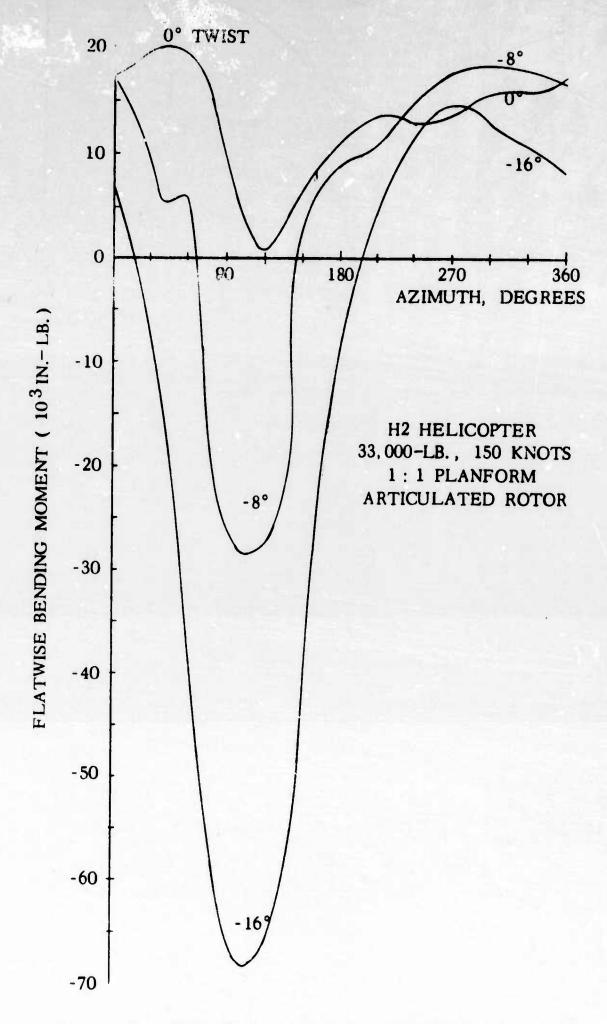


FIG. 7.40 CHANGE IN FLATWISE MOMENT WITH AZIMUTH FOR THREE VALUES OF TWIST

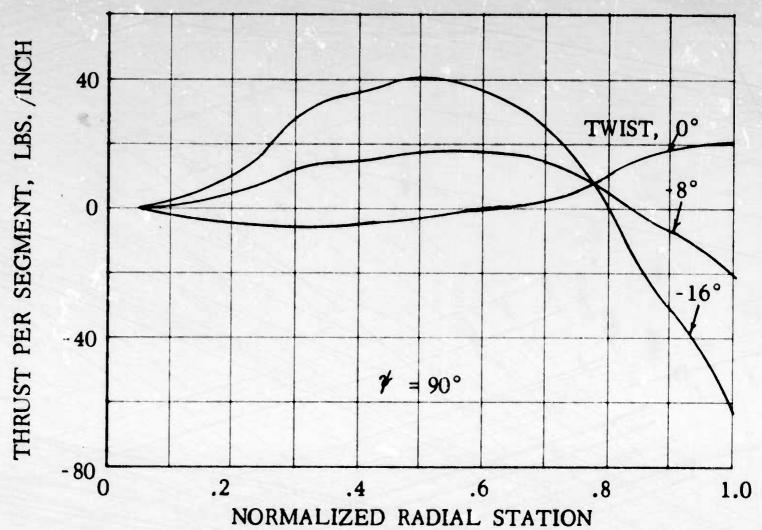


FIG. 7.41 CHANGE IN AIRLOAD DISTRIBUTION WITH TWIST

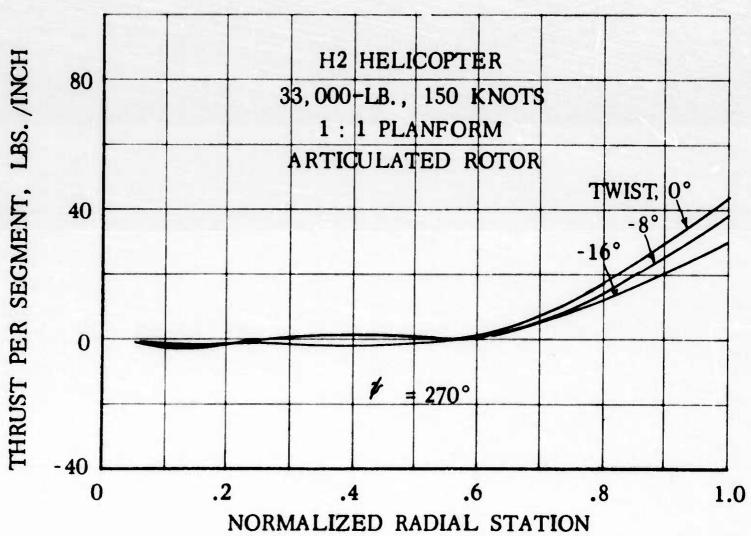


FIG. 7.42 CHANGE IN AIRLOAD DISTRIBUTION WITH TWIST

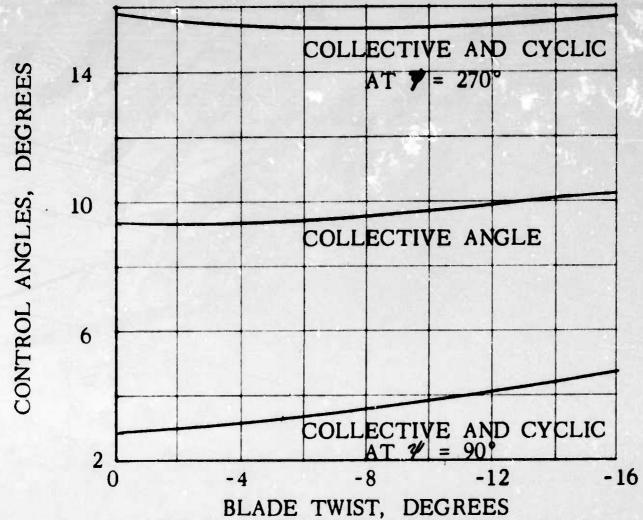


FIG. 7.43 CHANGE IN CONTROL ANGLES
WITH BLADE TWIST

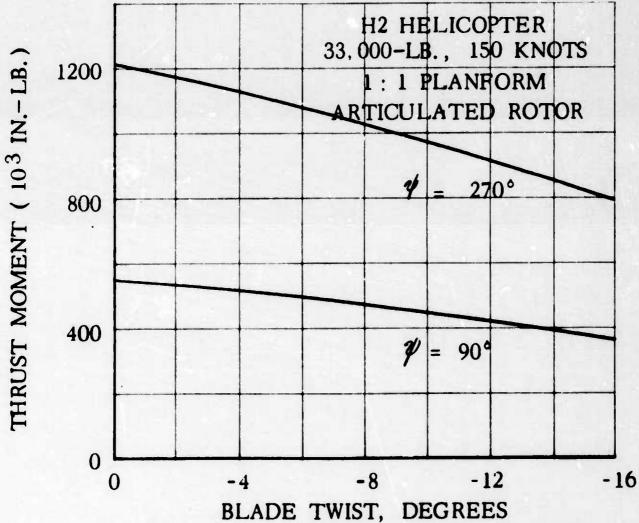
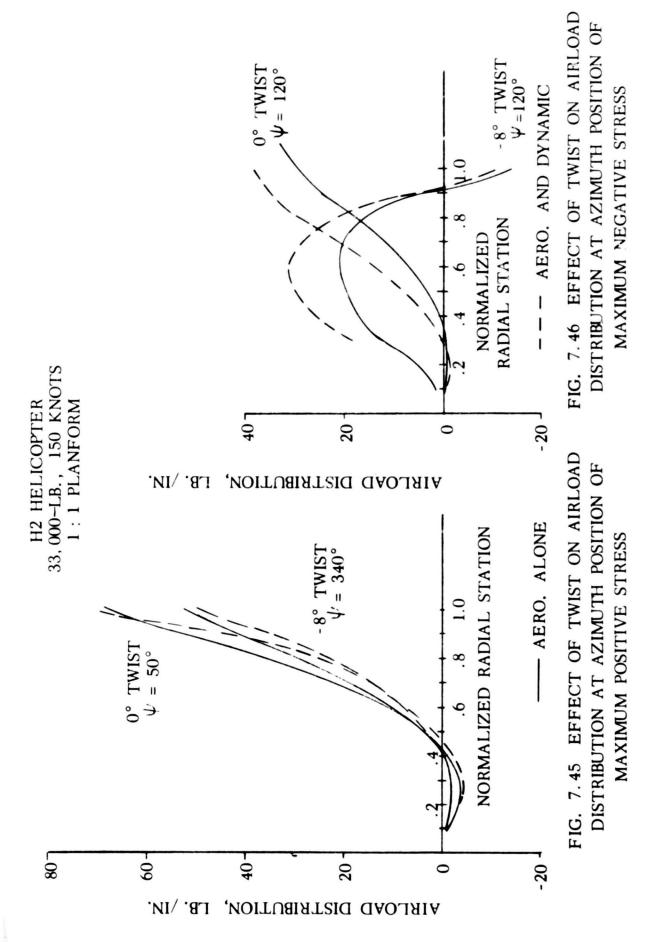
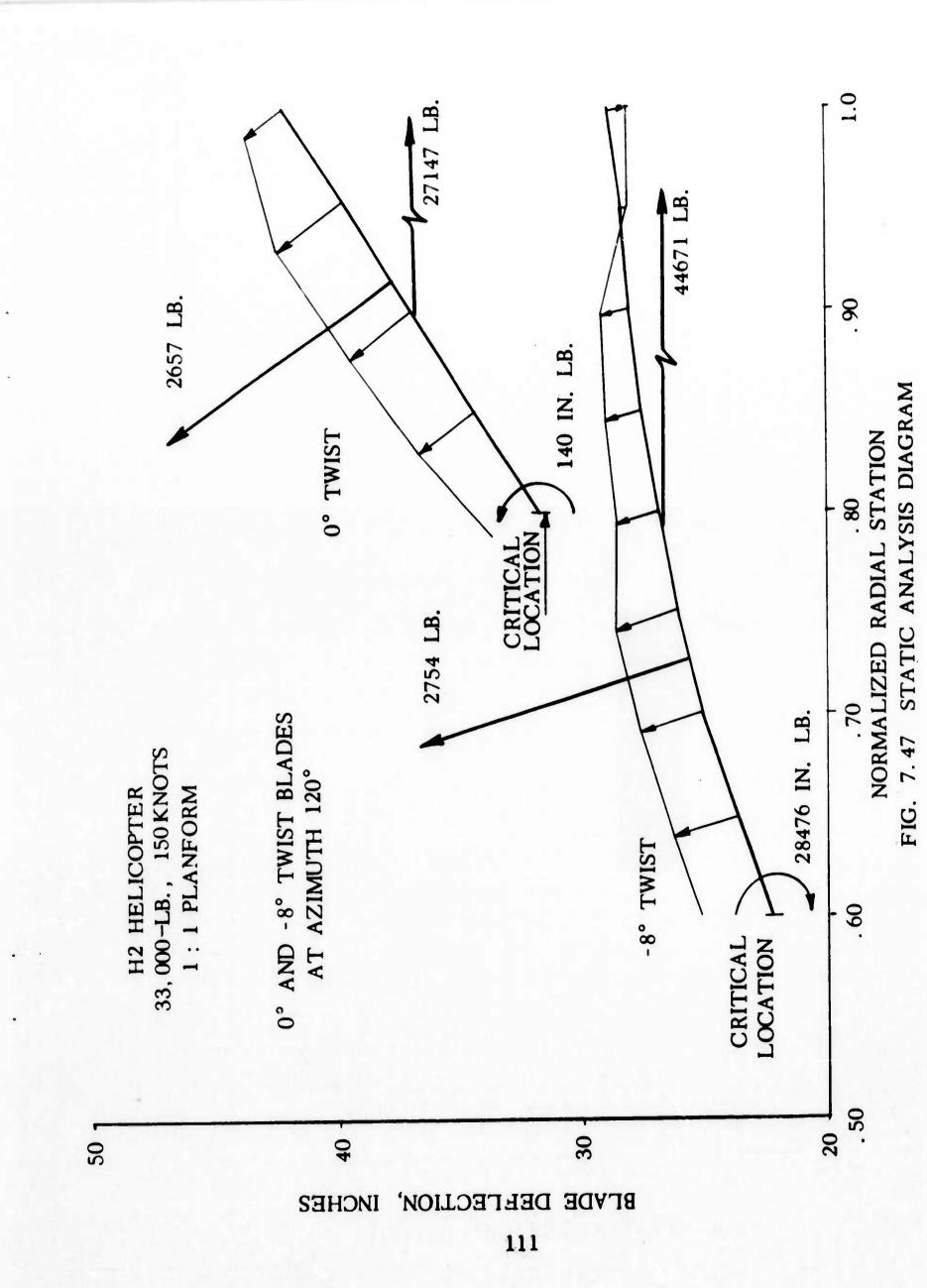
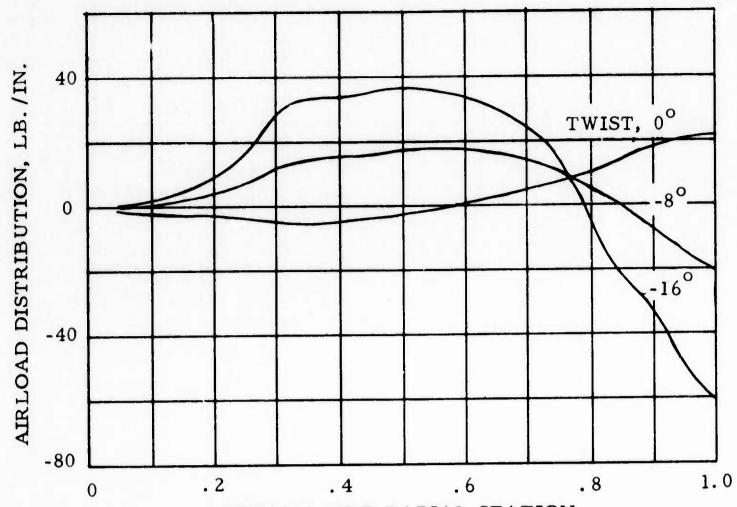


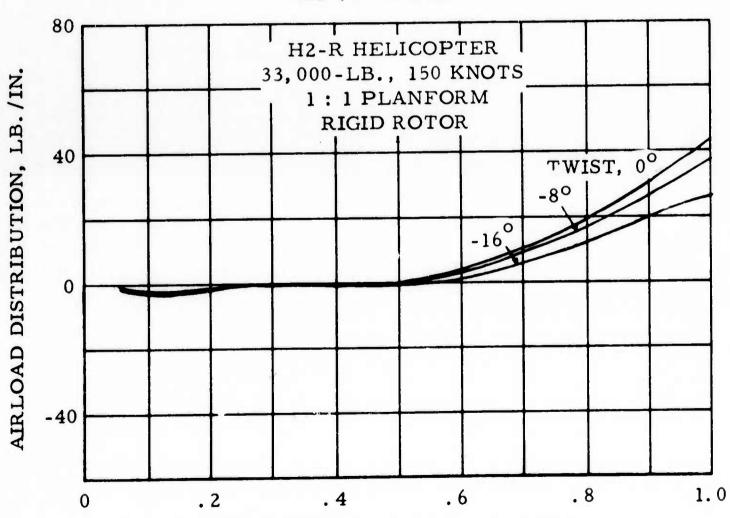
FIG. 7.44 CHANGE IN THRUST MOMENT WITH BLADE TWIST







NORMALIZED RADIAL STATION FIG. 7.48 CHANGE IN AIRLOADS WITH TWIST AT 90° AZIMUTH



NORMALIZED RADIAL STATION FIG. 7.49 CHANGE IN AIRLOADS WITH TWIST AT 270° AZIMUTH

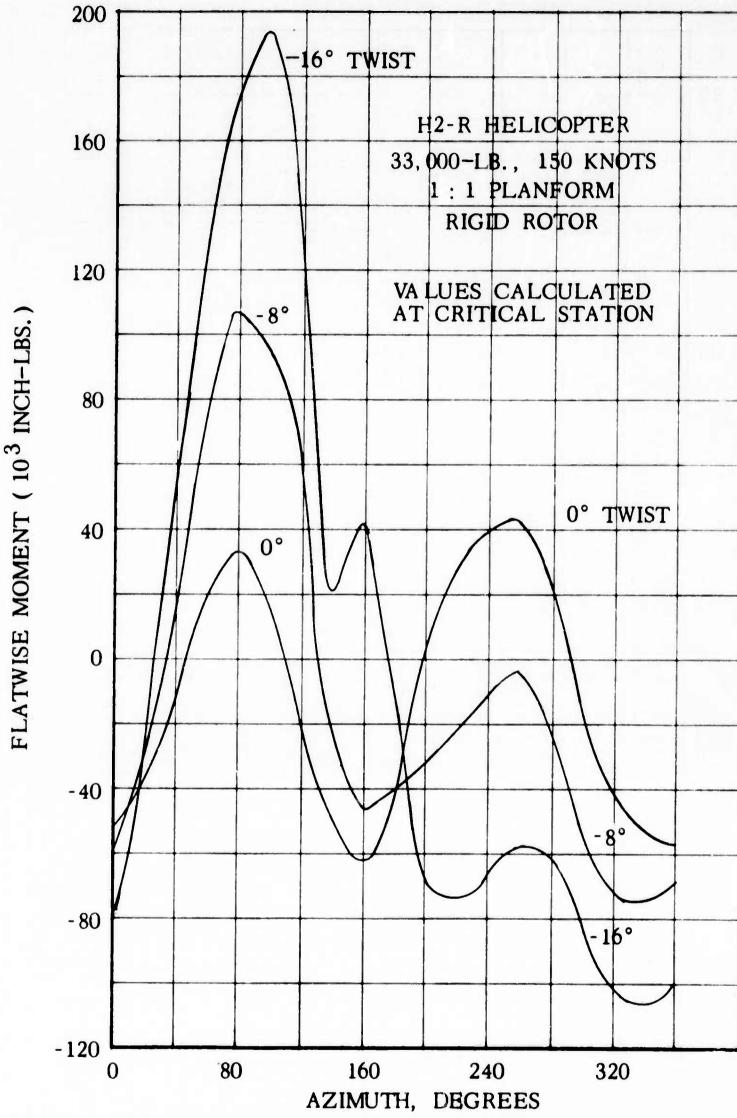


FIG. 7.50 CHANGE IN FLATWISE MOMENT WITH TWIST AND AZIMUTH

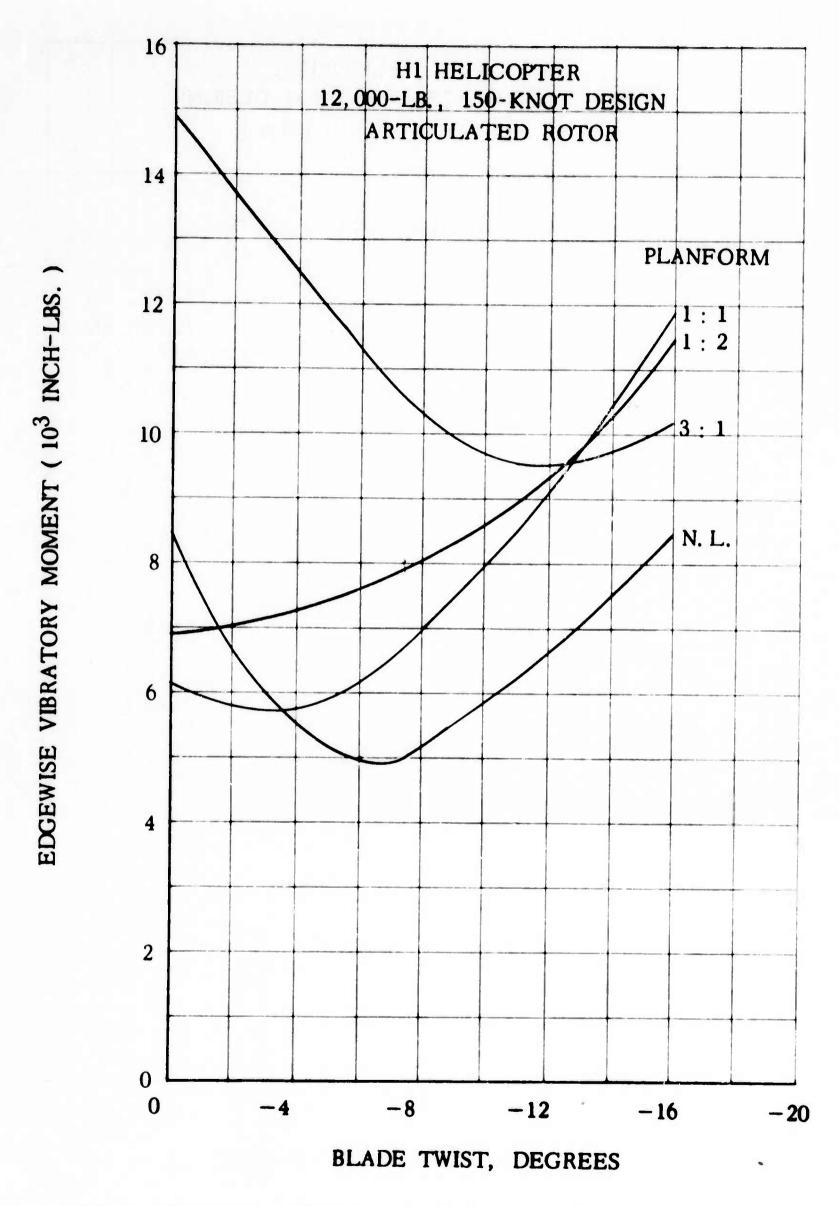


FIG.7.51 EFFECT OF TWIST ON EDGEWISE MOMENT

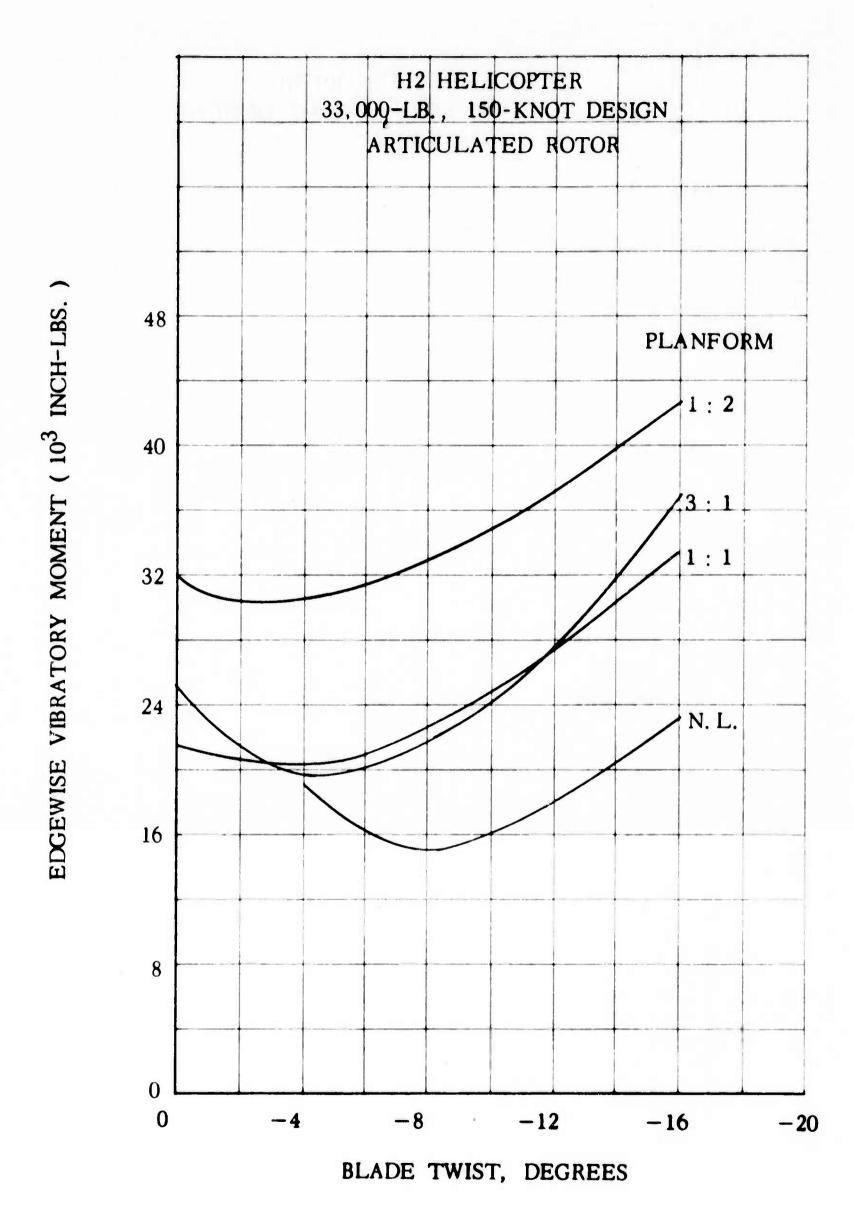


FIG. 7.52 EFFECT OF TWIST ON EDGEWISE MOMENT
115

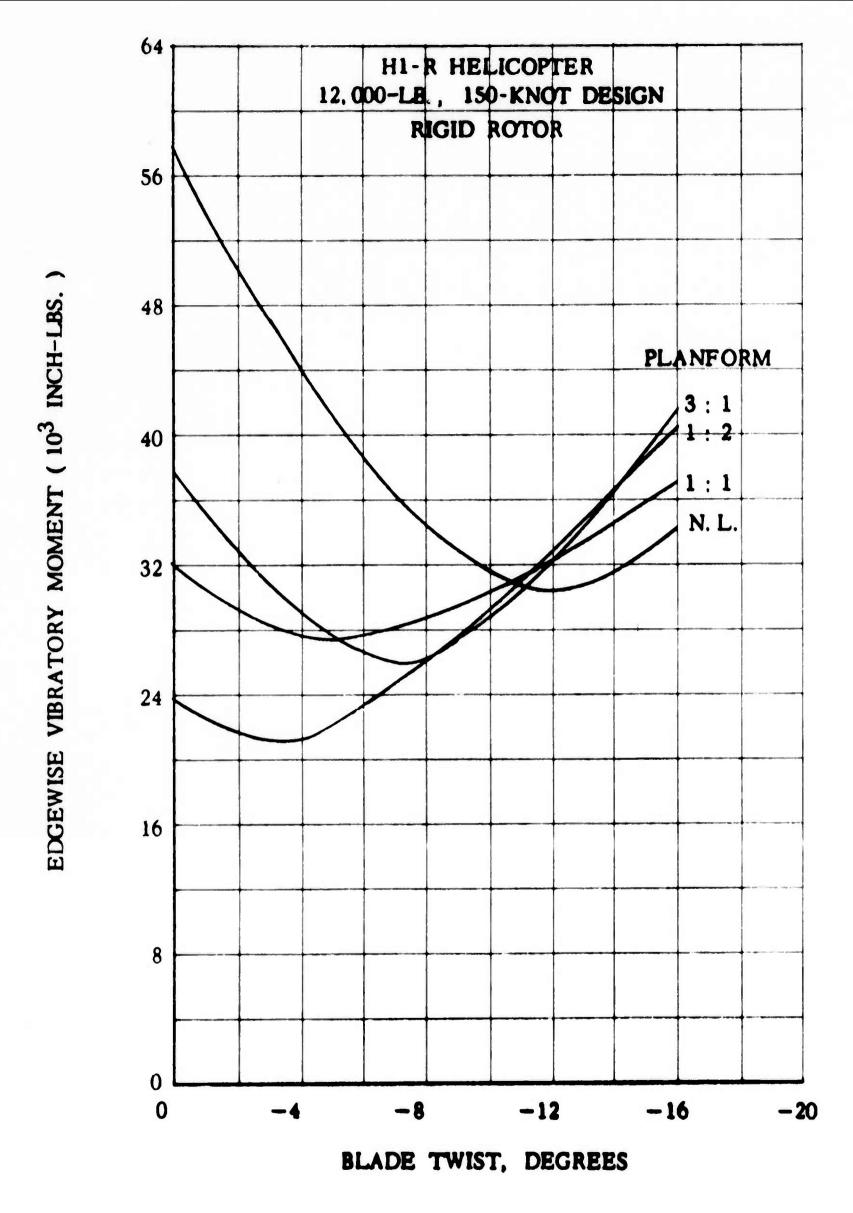


FIG. 7. 53 EFFECT OF TWIST ON EDGEWISE MOMENT 116

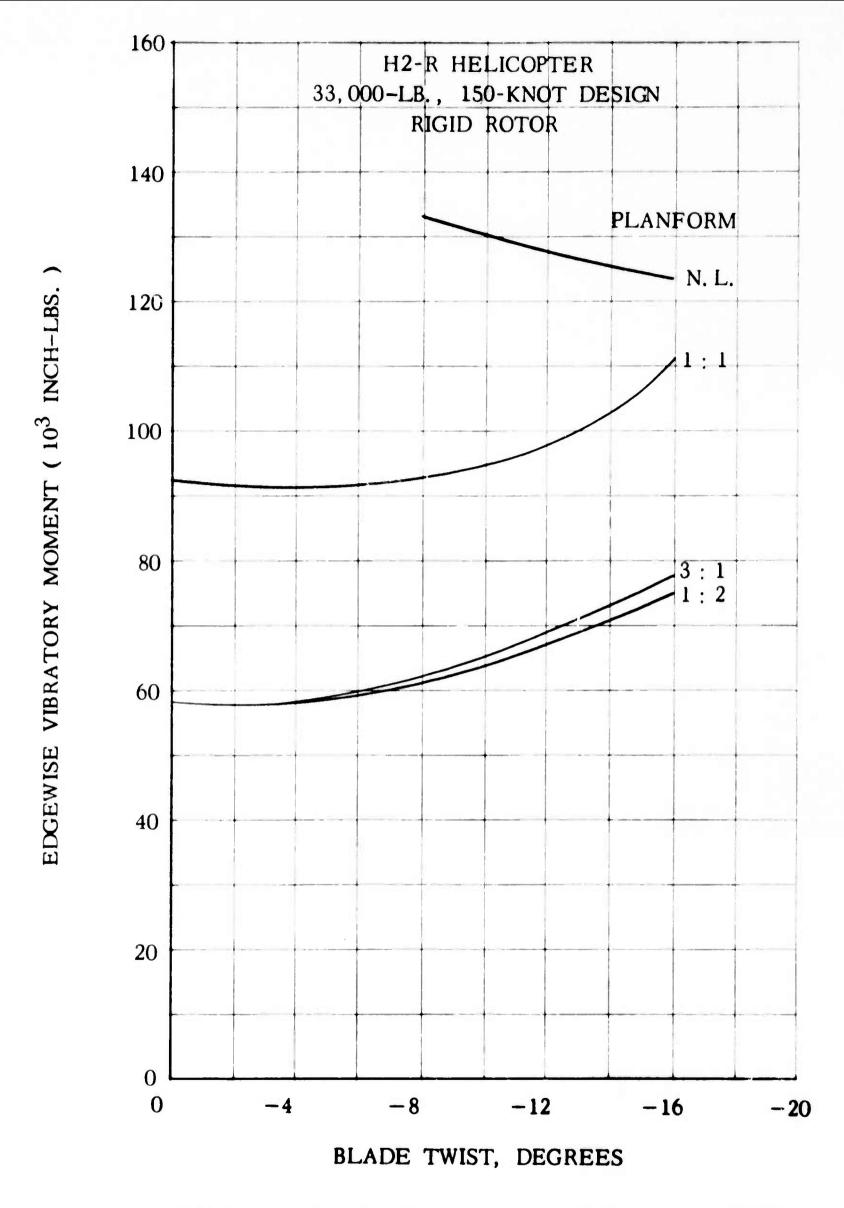
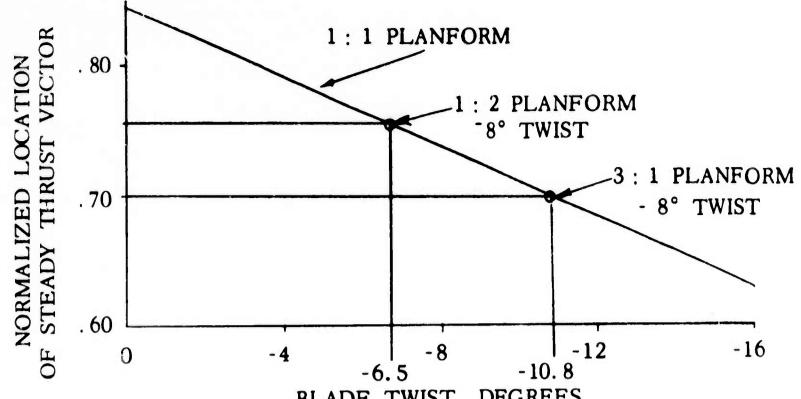


FIG. 7.54 EFFECT OF TWIST ON EDGEWISE MOMENT 117



BLADE TWIST, DEGREES FIG. 7.55 CHANGE IN LOCATION OF RESULTANT STEADY THRUST VECTOR WITH CHANGE IN TWIST

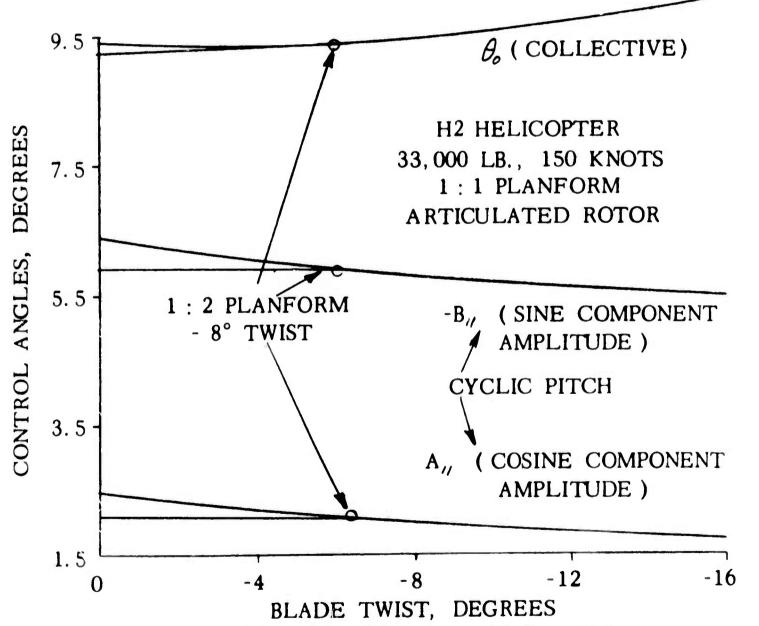
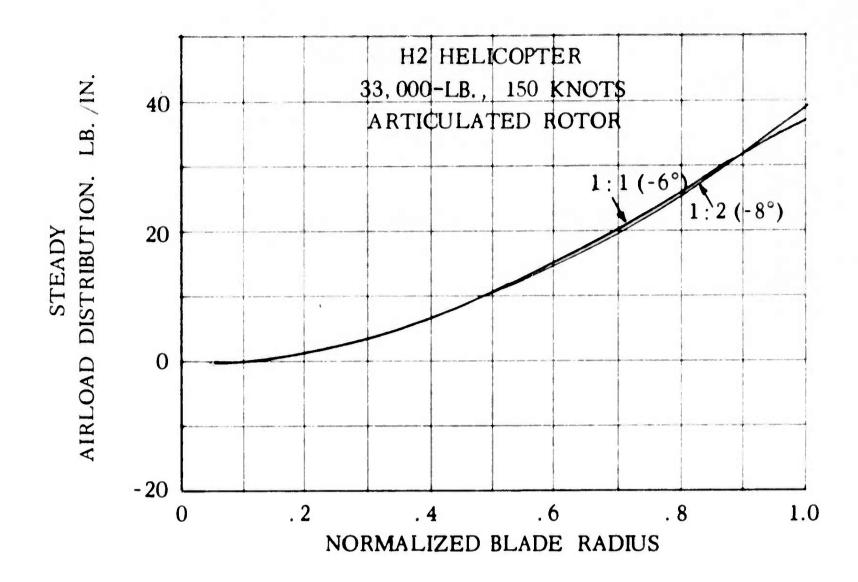


FIG. 7.56 CHANGE IN CONTROL ANGLES
WITH CHANGE IN TWIST



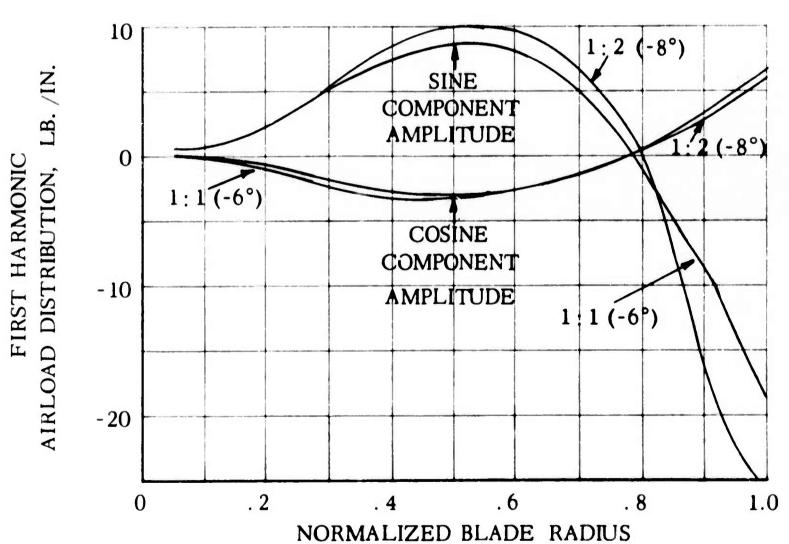


FIG. 7.57 CHANGE IN AIRLOAD DISTRIBUTION WITH TWIST

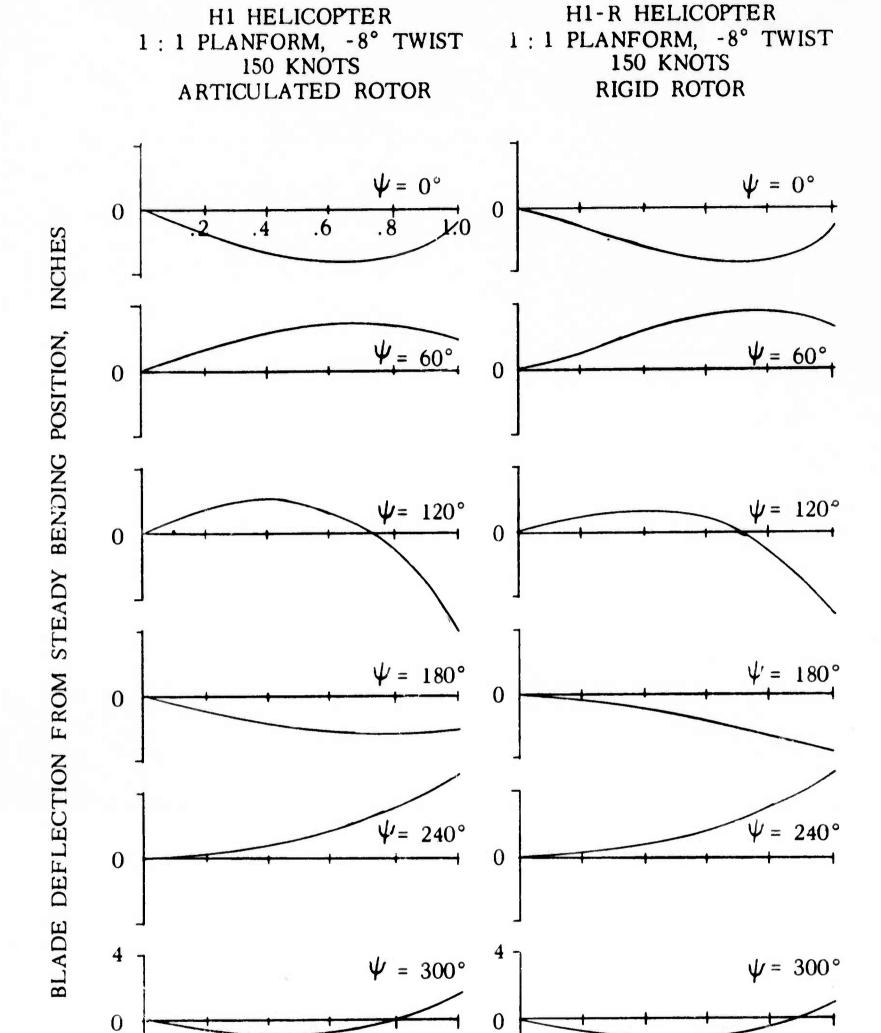
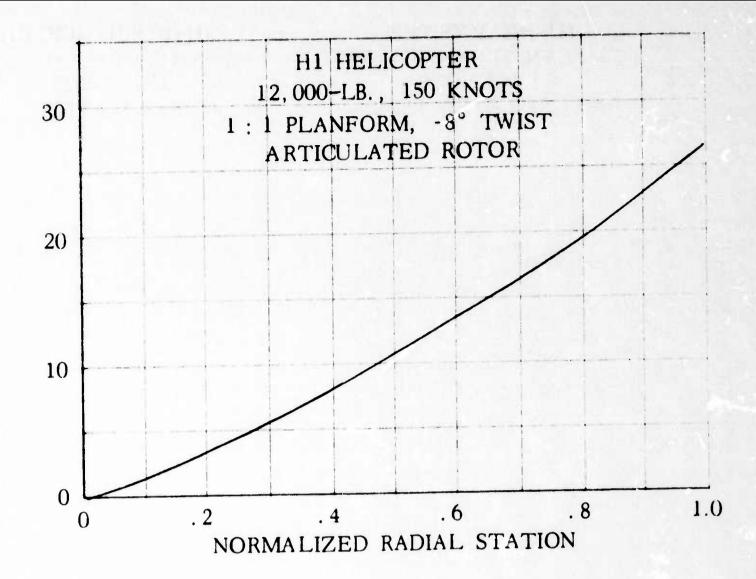
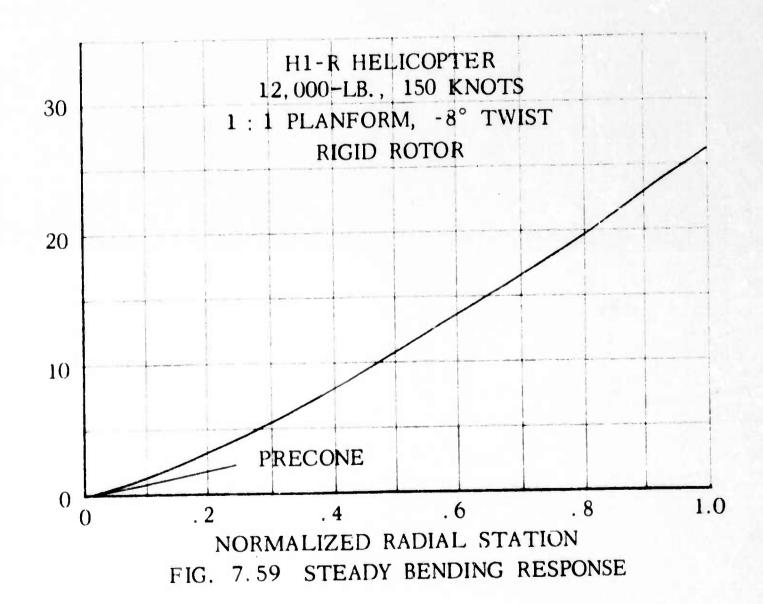


FIG. 7.58 CHANGE IN BLADE DEFLECTION WITH AZIMUTH

-4

-4





## 8. AERODYNAMIC PARAMETER VARIATIONS

## A. FUSELAGE DRAG

Tables 2. 7 and 2. 8 give the schedule of fuselage drag variations investigated in the program. Rotor power with drag change is plotted versus airspeed in Figure 8. 1. As expected, the plot shows both increased power with forward speed and increased power with increased fuselage drag. Similar trends are shown for both high-gross-weight and low-gross-weight helicopters.

Presented in Figures 8. 2 through 8. 5 are effects of fuselage drag variation on flatwise blade vibratory moments. Results are given for both high-gross-weight and low-gross-weight helicopters with articulated and rigid rotor systems. With equivalent changes in fuselage drag, smaller vibratory moment variations were noted for the articulated than for the rigid rotor system. For gross weights, airspeeds, and blade systems considered, no consistent trend of moment increase or decrease with change in drag was observed.

## B. VARIATIONS IN ROTOR SPEED

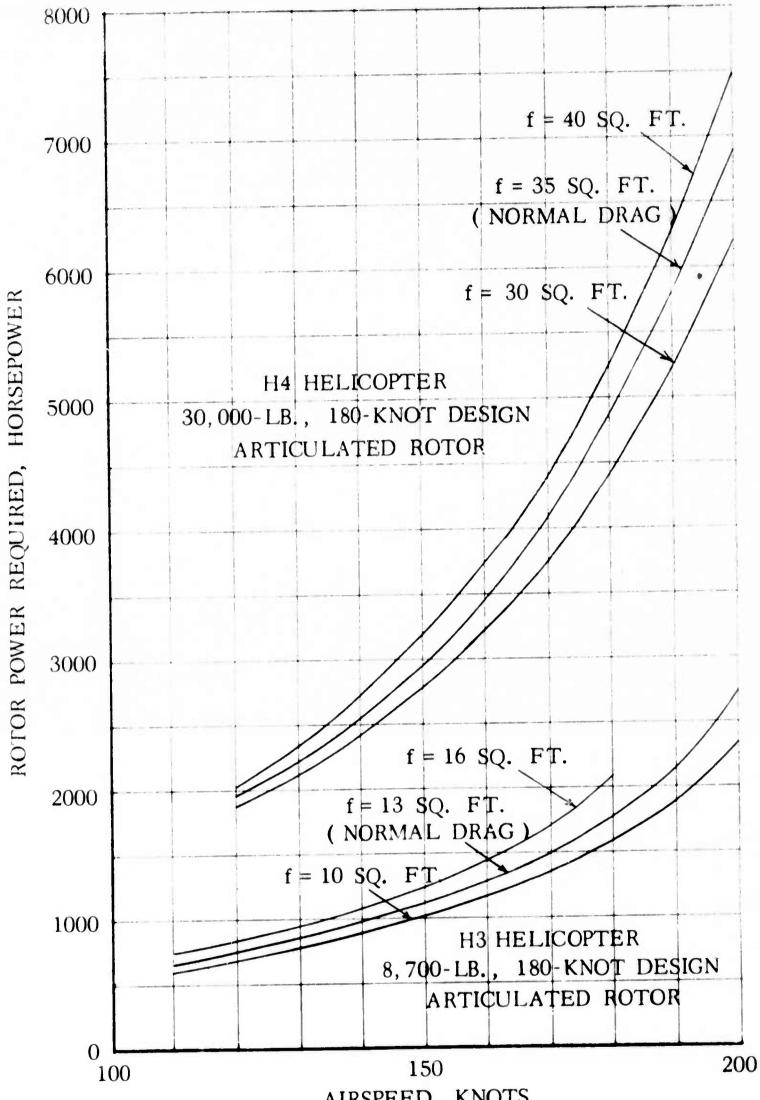
Variations in rotor rpm were carried out according to the schedule given in Table 2. 2. Shown in Figures 8. 10 and 8. 11 are effects of rpm changes on rotor power and blade moments with airspeed held constant at 250 knots. Results are shown for both the C3 and C3-R compound helicopters. Observe that while there is a decrease in vibratory blade moment with increase in rpm, there is a corresponding increase in power required. Again, stress and power requirements are incompatible, and the design solution must be a compromise of the two. Also, note the sharp gradients of the curves. These indicate that rpm variations at high speeds for compound helicopters will result in sharp changes in power requirements and blade stress.

Effects of airspeed and rpm variations are shown in Figures 8. 6 through 8. 9. Plotted are resulting power and vibratory bending moments for the three rotor speeds considered. Observe that slopes of the power-rotor speed curves and stress-rotor speed curves increase with increase in air-speed. This means that the power-stress compromise becomes more critical as airspeed increases.

## C. ALTITUDE VARIATIONS

The schedule of altitude conditions is presented in Tables 2.7 and 2.8. Figures 8.12 through 8.15 plot change in main rotor power required with altitude. Differences in sea-level power for articulated and rigid rotor helicopters are due to differences in blade twist. Design twist for rigid and articulated blades was based upon standard design practice of respective manufacturers.

• Changes in blade vibratory moments with altitude are shown in Figures 8. 16 through 8. 19. Results which are presented take into account change in fuselage attitude with altitude, as well as air density and Mach number effects. Change in fuselage attitude affects both equivalent flat-plate area of the fuselage and rotor lift requirements. Data showing the variation in fuselage lift and drag with airspeed and altitude are presented in Appendix A.



AIRSPEED, KNOTS FIG. 8.1 CHANGE IN POWER REQUIRED WITH PARASITE DRAG

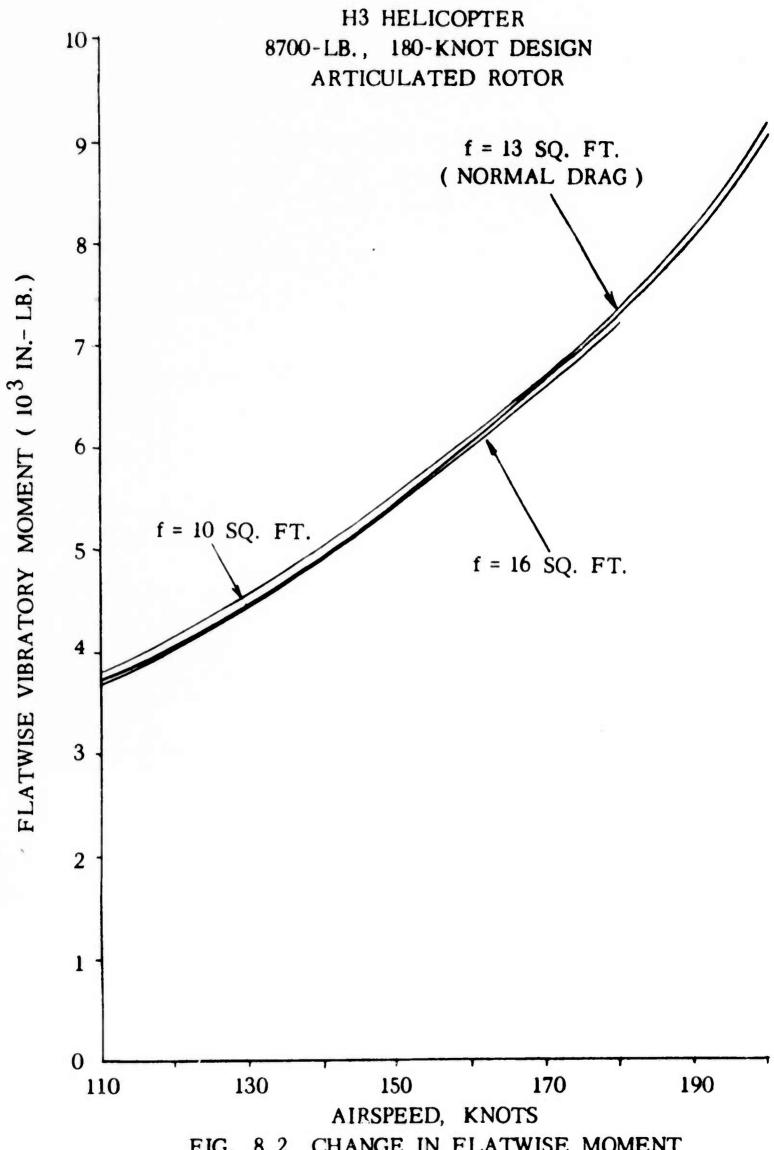


FIG. 8.2 CHANGE IN FLATWISE MOMENT WITH PARASITE DRAG

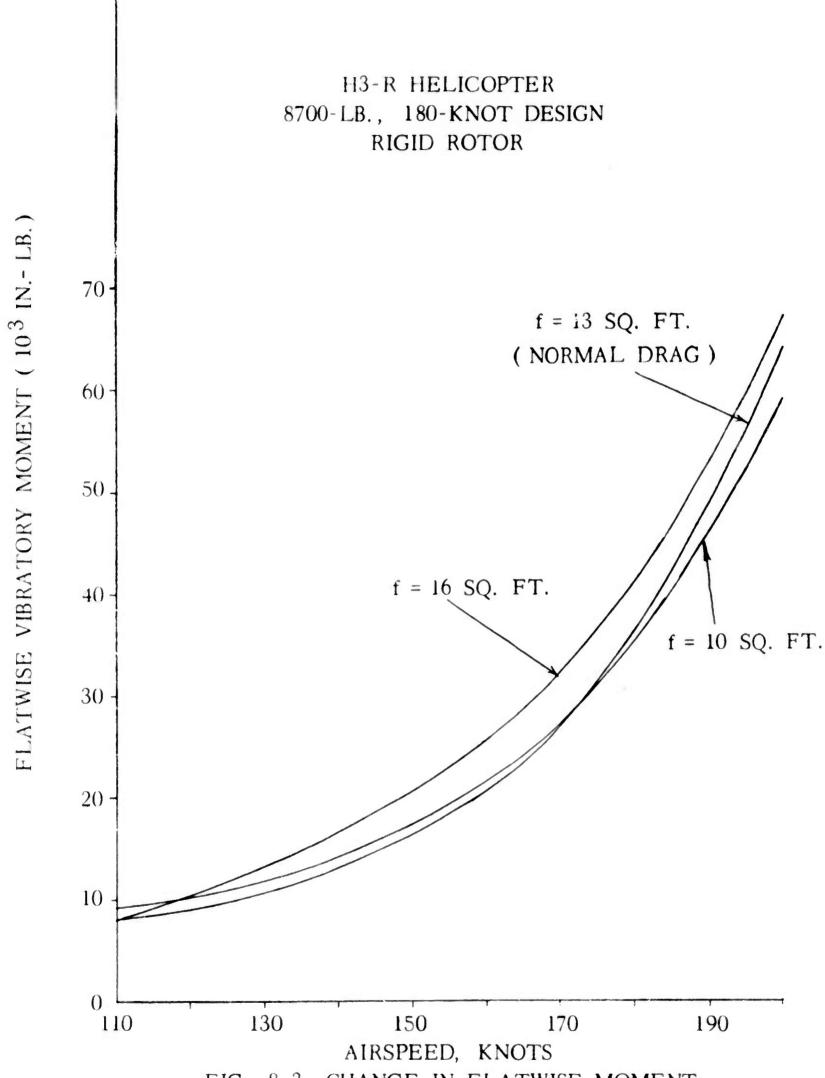


FIG. 8.3 CHANGE IN FLATWISE MOMENT WITH PARASITE DRAG

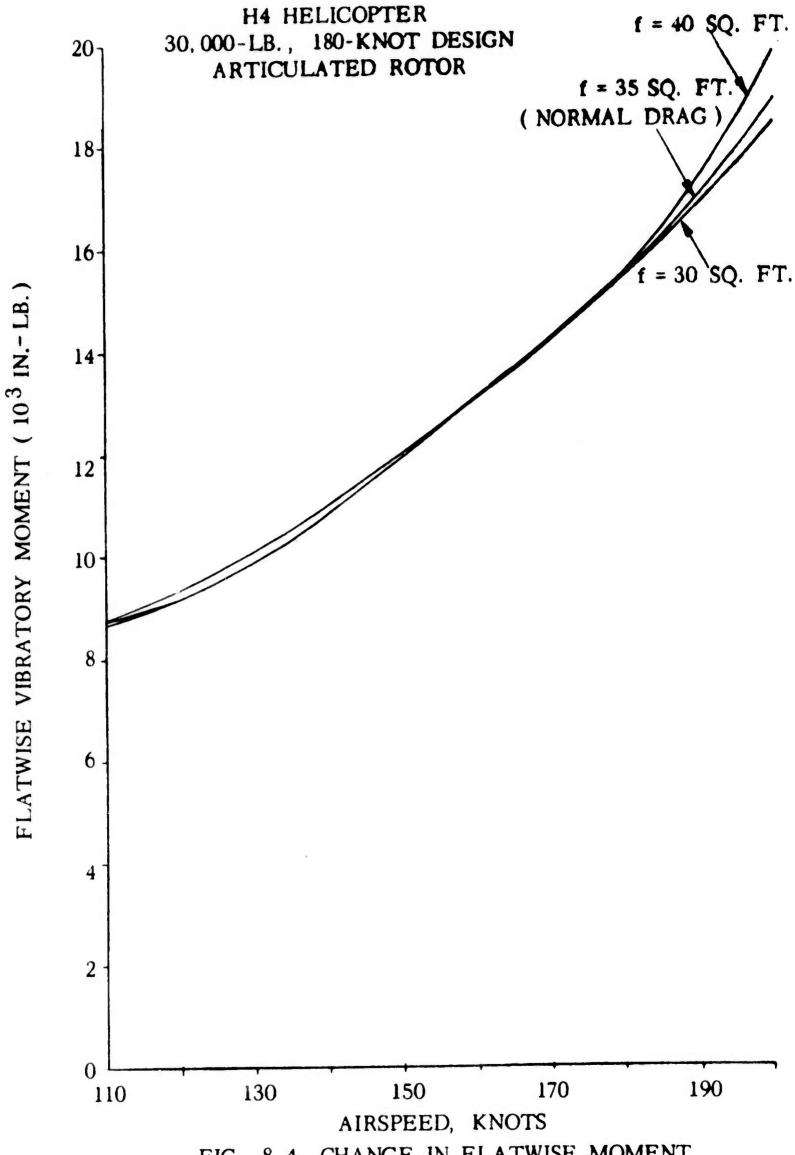


FIG. 8.4 CHANGE IN FLATWISE MOMENT WITH PARASITE DRAG

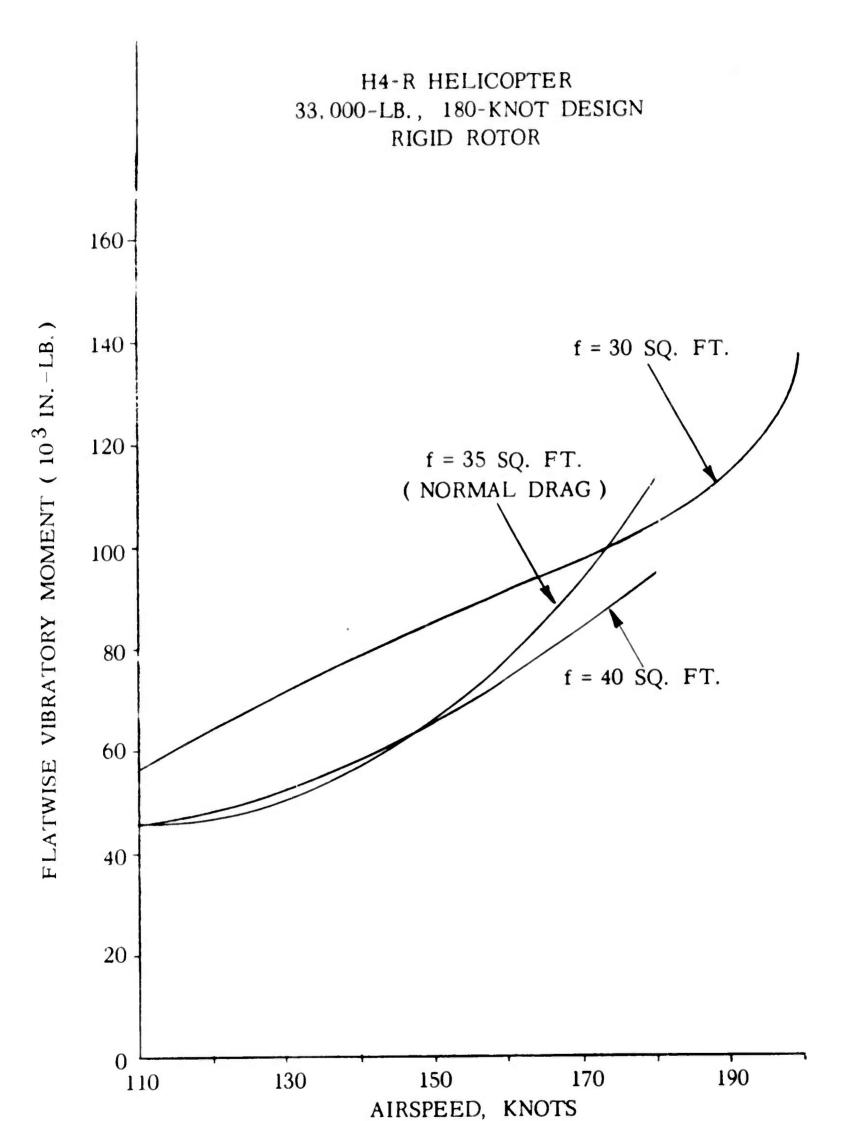


FIG. 8.5 CHANGE IN FLATWISE MOMENT WITH PARASITE DRAG
129

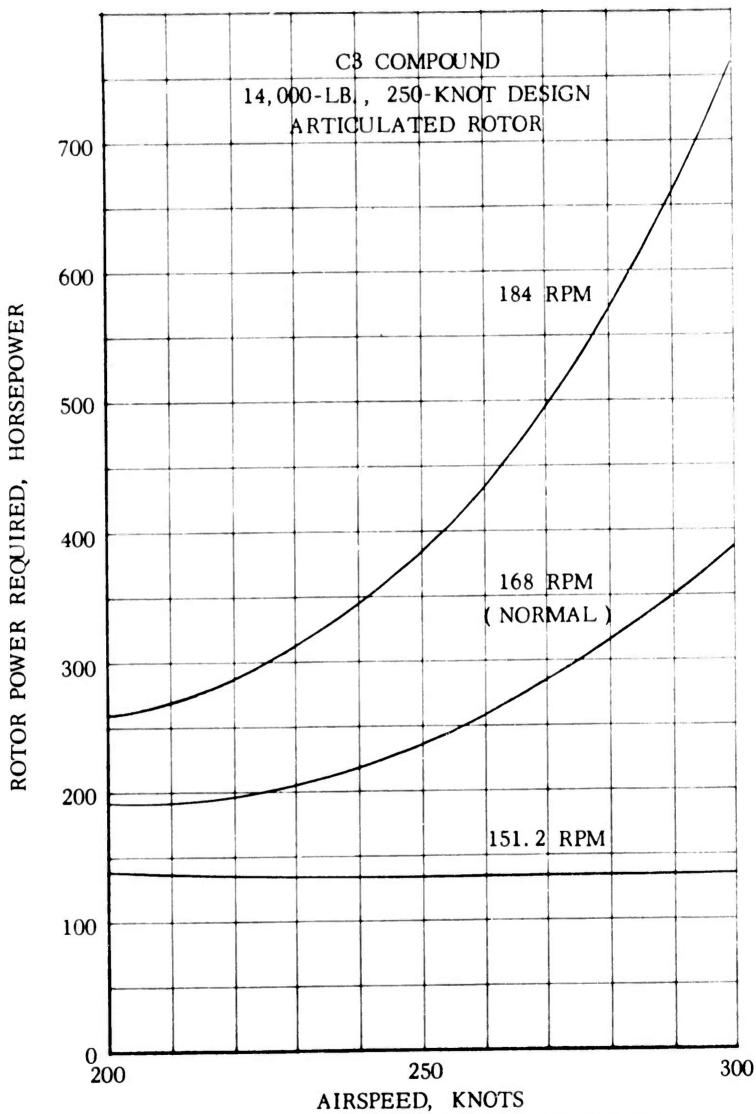
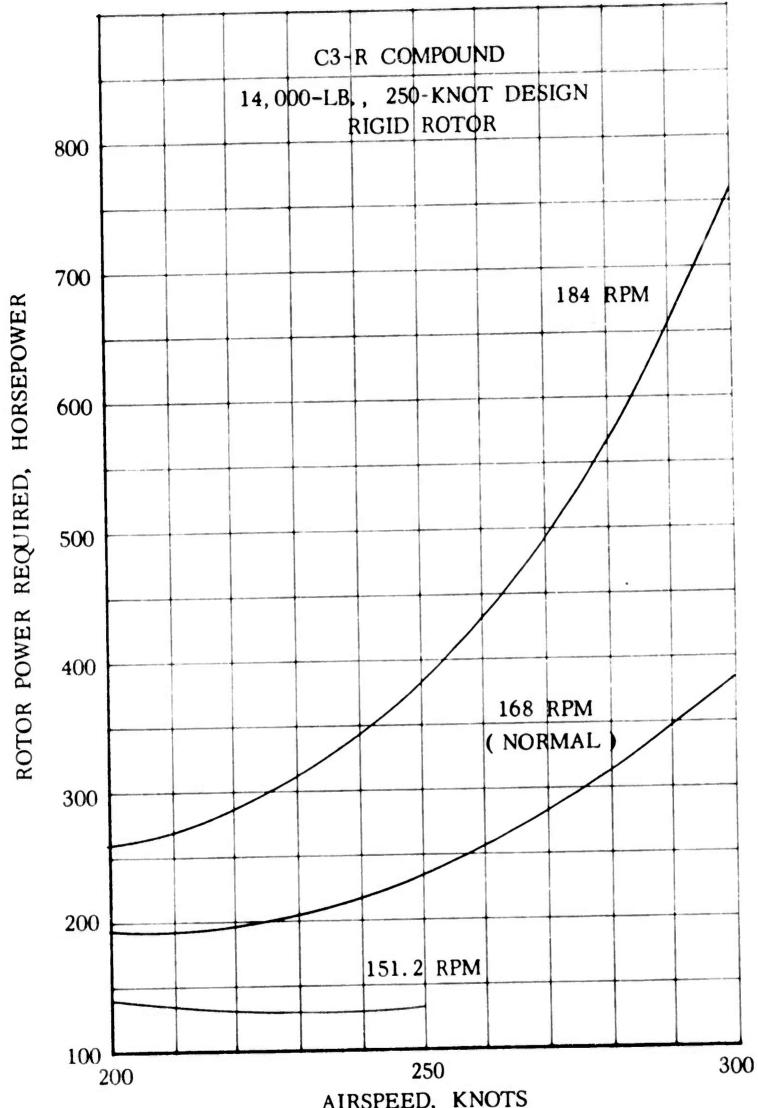


FIG. 8.6 CHANGE IN POWER REQUIRED WITH ROTOR SPEED



AIRSPEED, KNOTS FIG. 8.7 CHANGE IN POWER REQUIRED WITH ROTOR SPEED

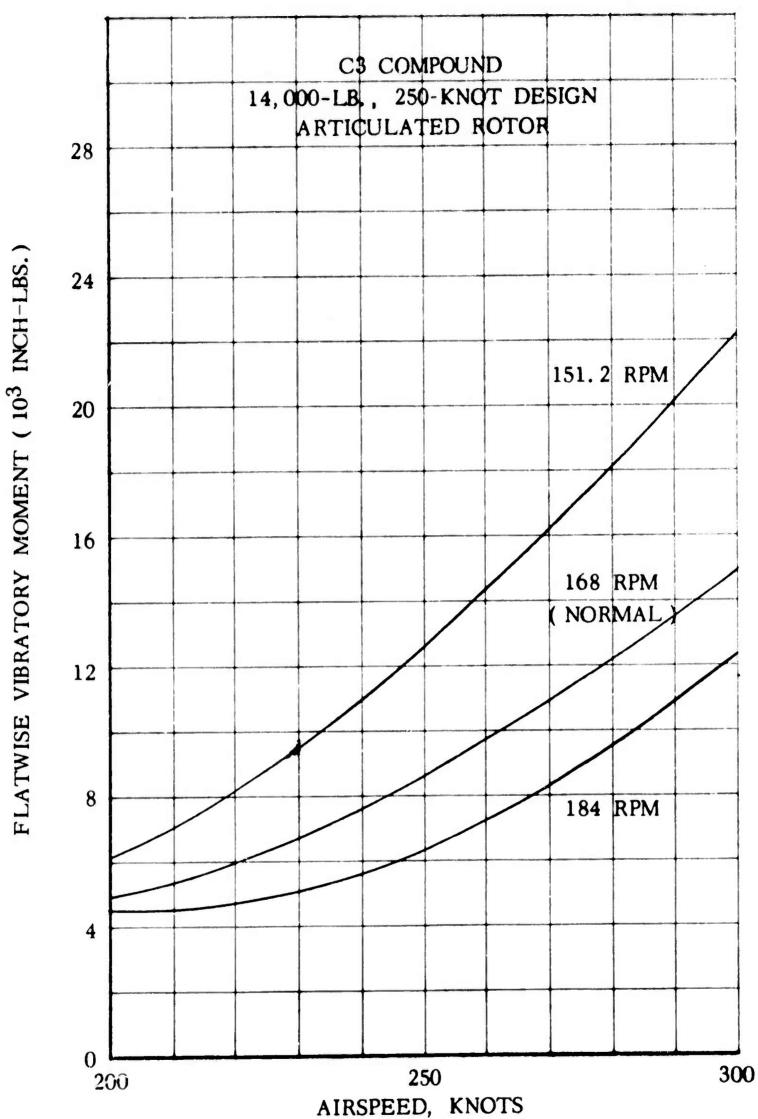


FIG. 8.8 CHANGE IN FLATWISE MOMENT WITH ROTOR SPEED

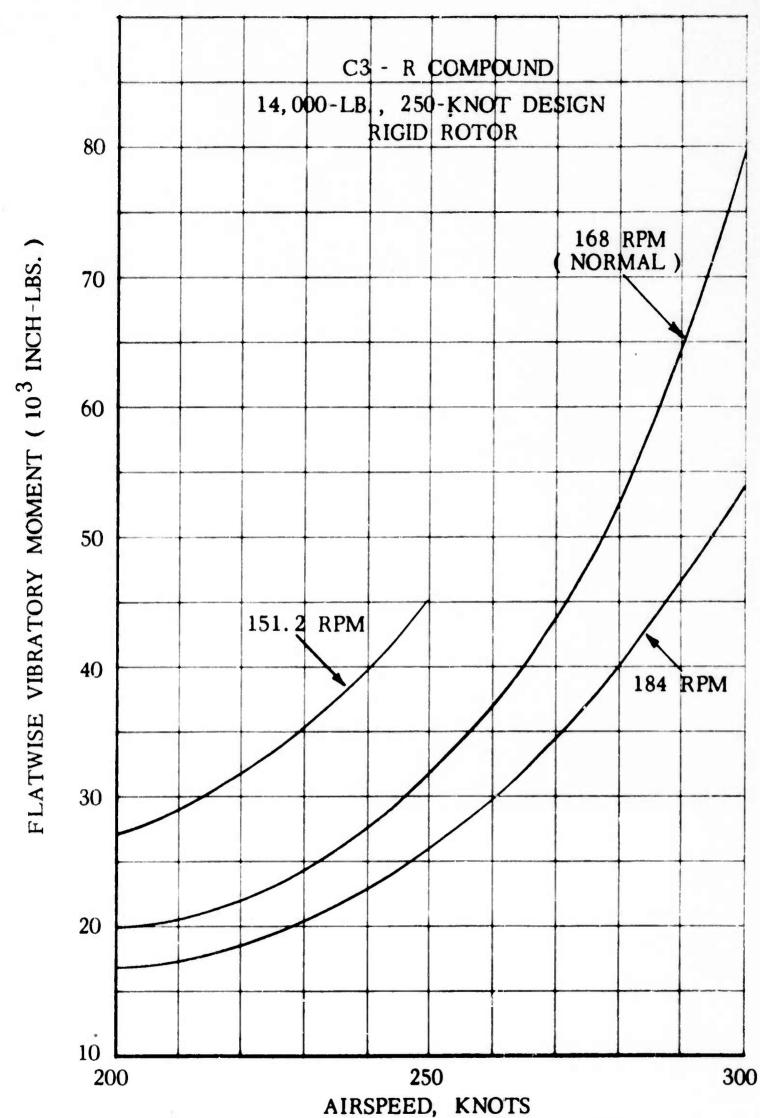
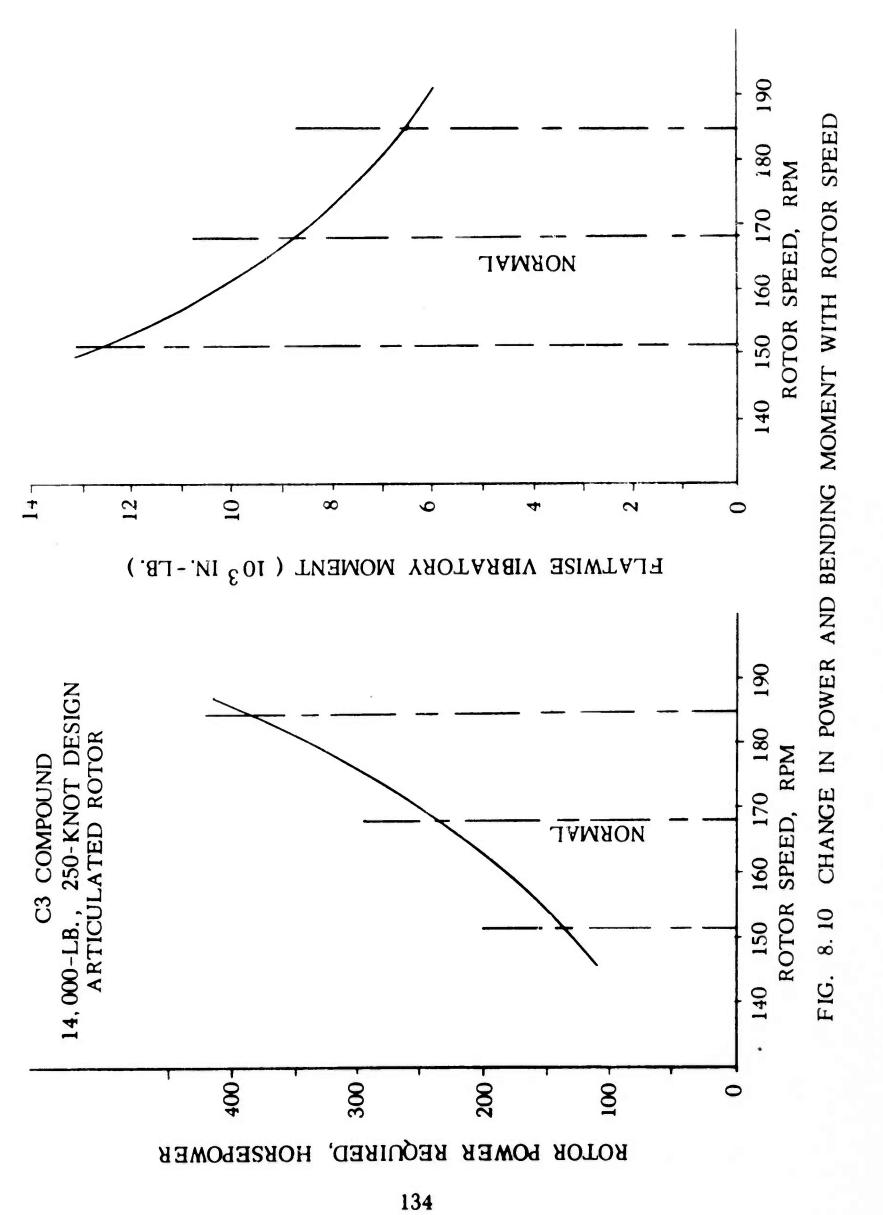
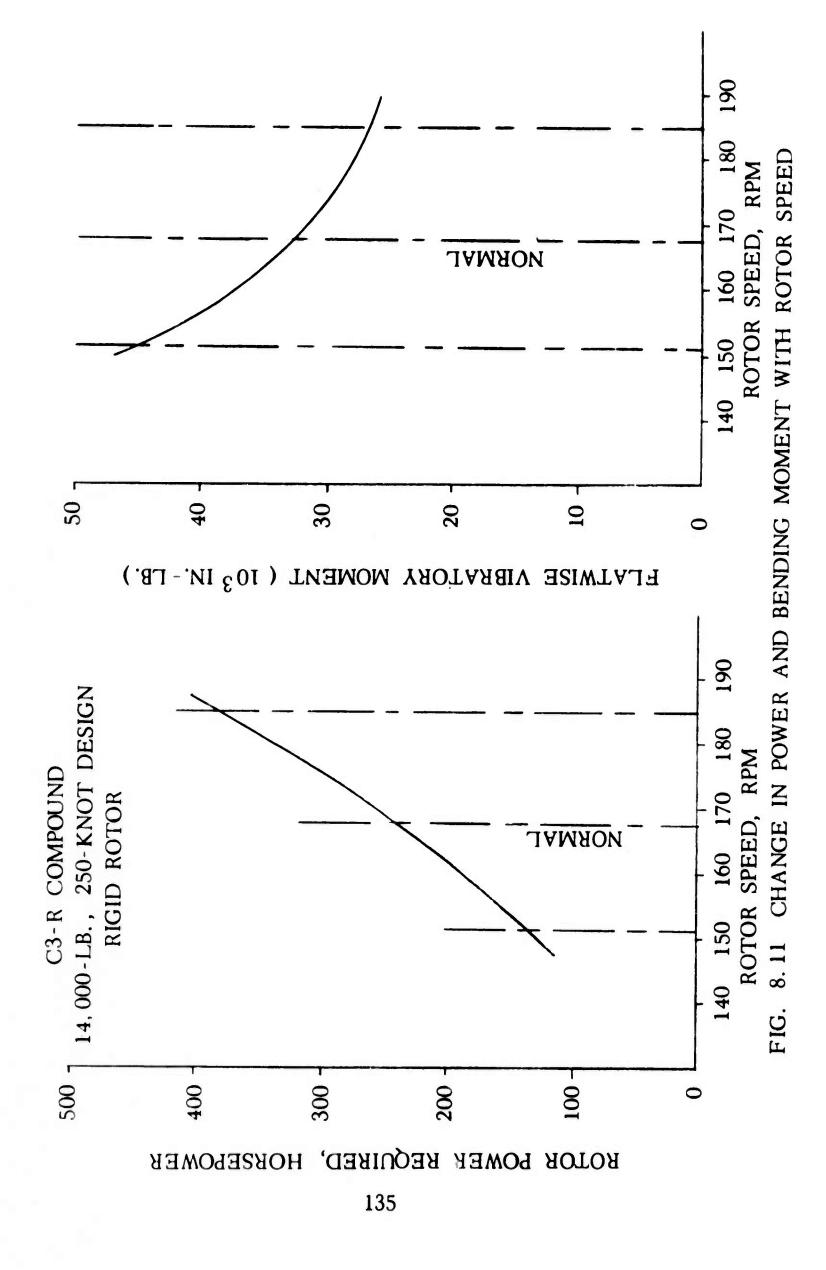
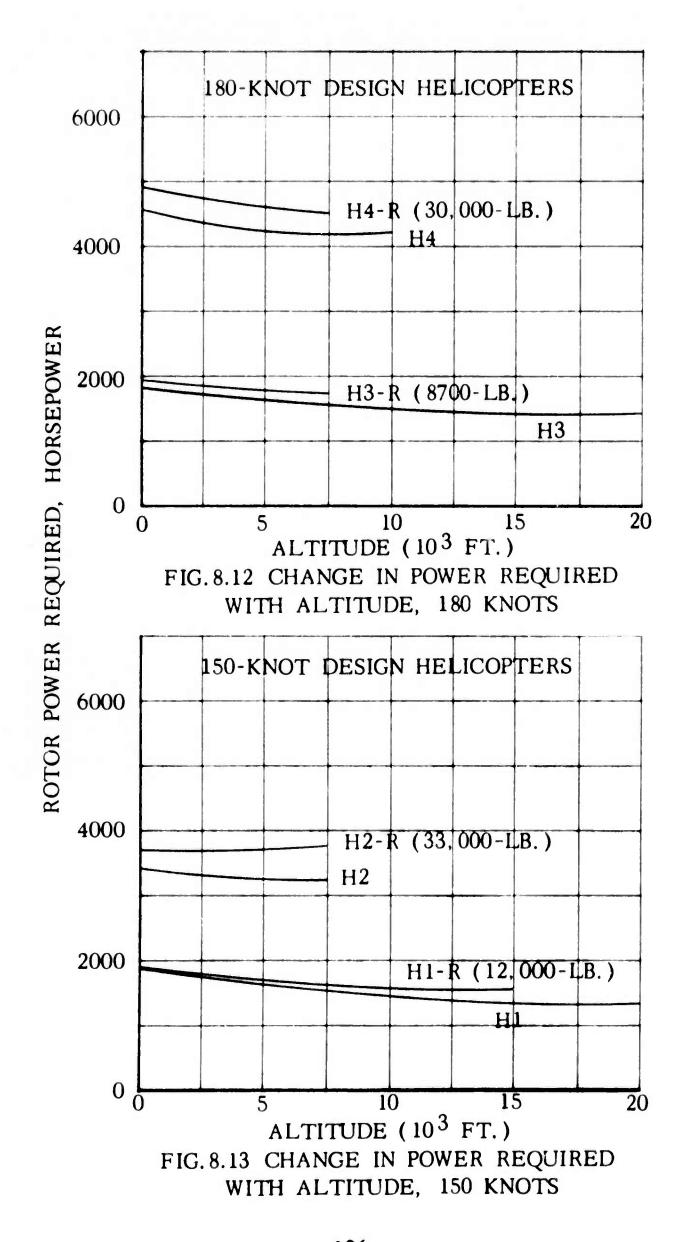
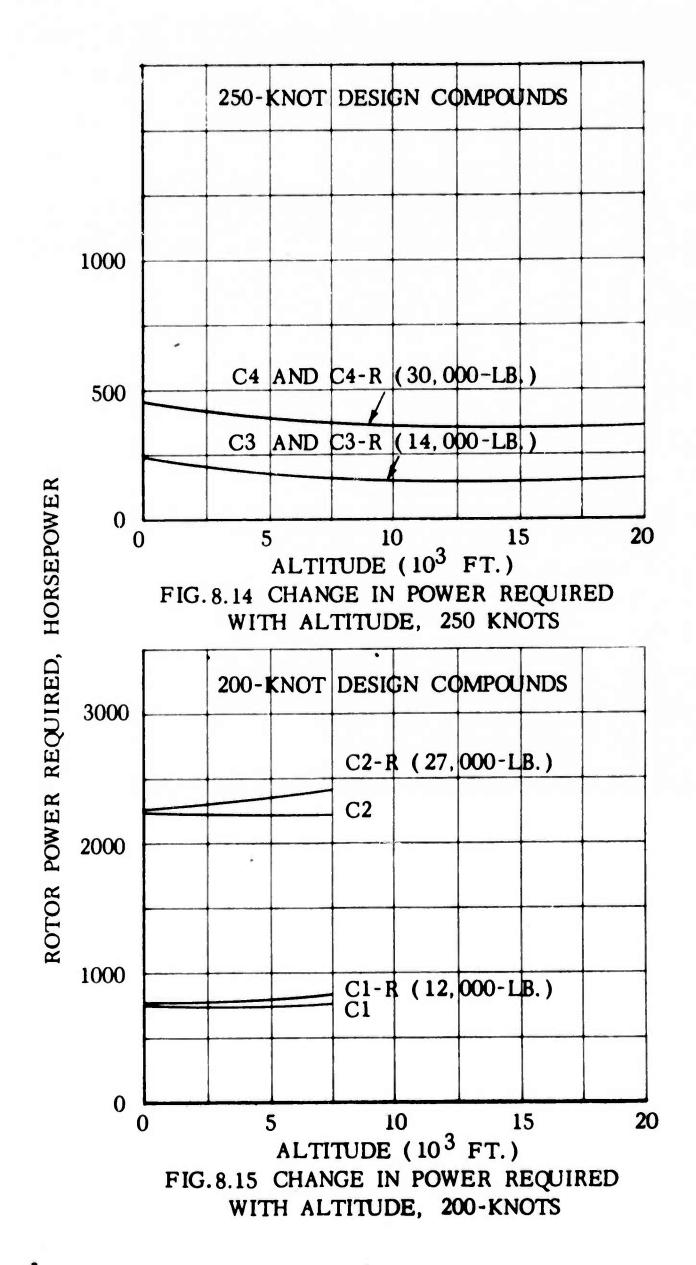


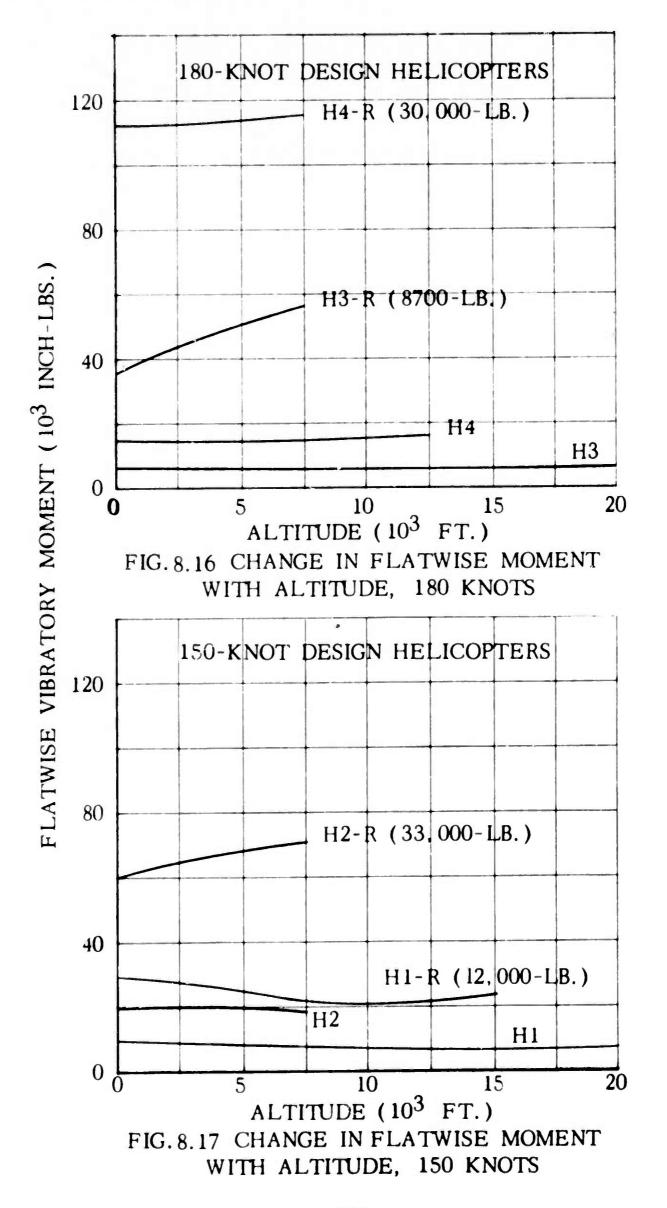
FIG. 8.9 CHANGE IN FLATWISE MOMENT WITH ROTOR SPEED

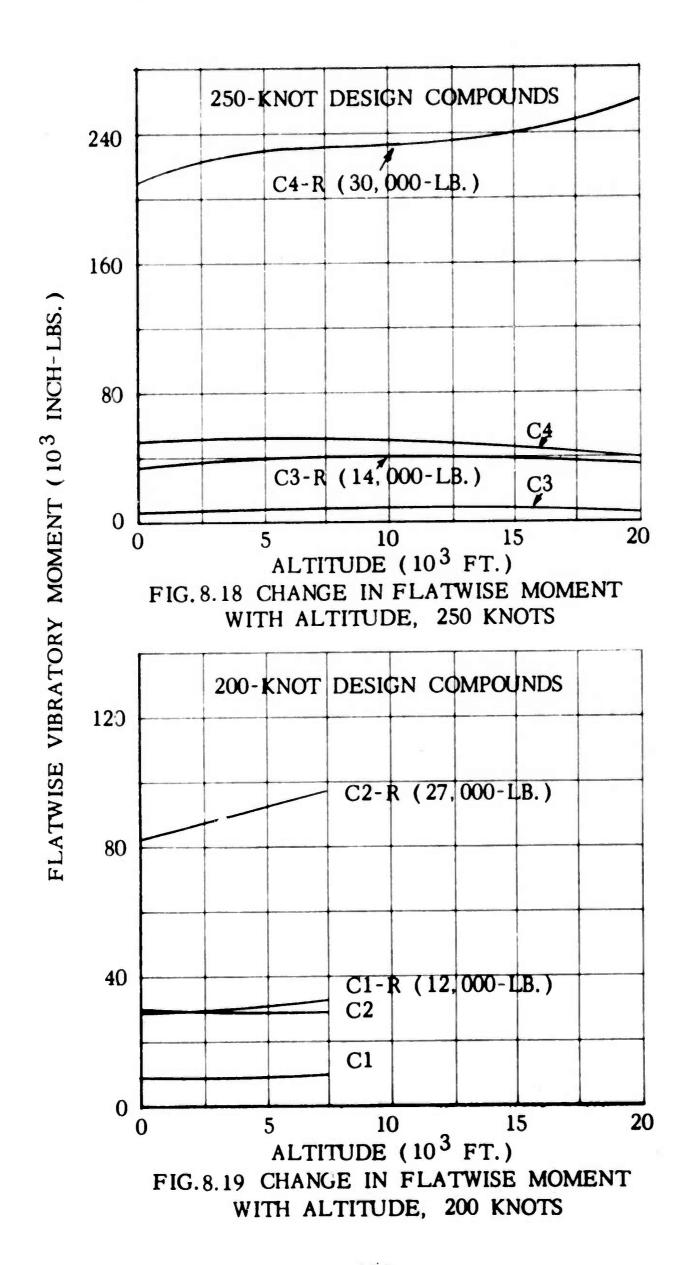












## 9. VARIATION OF BLADE STIFFNESS

Variations in blade stiffness are presented in the schedule given by Table 2.3. Figures 9.1 through 9.4 give results of the study for the 150-knot, 33,000-pound helicopter. In Figures 9.1 and 9.2, flatwise stiffness of the basic blade has been both doubled and reduced by one-half. For the articulated case, the entire moment envelope is seen to increase with increase in stiffness. The same is observed for the rigid blade in the root region. For this case, it is interesting to note that the point of minimum bending moment moves inboard as the blade becomes more flexible. These are typical of the envelopes at each air-speed considered.

Effects of linear variation of stiffness about the basic blade design are given by Figures 9. 3 and 9. 4. Here, flatwise stiffness has been multiplied by factors ranging linearly from 2 at the root to 1/2 at the tip and vice versa. For the articulated blade, the standard design gave lowest vibratory moments as shown by Figure 9. 3. Here, stiffened outboard blade section and softened cuff appear most detrimental. For rigid blades (Figure 9. 4), where the critical region is at the root, the reverse is true. Low root stiffness contributes to lower moments, and the stiffer outboard section does not have a significant detrimental effect.

Figures 9. 5 and 9. 6 show effects of airspeed on maximum flatwise vibratory moments for the stiffness variations just discussed. Results are presented for both rigid and articulated rotor systems. Trends with airspeed are as expected. Increased airspeed results in increased one-per-rev airload dissymmetry. This, in turn, produces increased vibratory moments. Sequence of stiffness variations on a vibratory moment basis did not change with airspeed.

Effects of stiffness distribution on blade vibratory moments can be understood by study of basic beam bending relationships. Vibratory moments can be expressed by:

$$M_{V/B} = E I \left[ \frac{\partial^2 y}{\partial x^2} \right]_{V/B}$$

Or, in terms of the standard blade:

Note that vibratory moment at a blade station is directly proportional to section stiffness and vibratory curvature at that station. Curvature is determined by stiffness, centrifugal loads, and applied aerodynamic plus inertia loads. Azimuth histories of curvature for ratios of  $I/I_{\rm O}$  1, 2, and 1/2 are shown in Figure 9.7 for the H2 helicopter. Curvature is plotted at the critical blade station. Observe that as  $I/I_{\rm O}$  increases, there is an associated decrease in vibratory curvature. In other words, the net vibratory moment is a tradeoff between the increase in I and the decrease in curvature. For rotor systems considered here, Figures 9.8 and 9.9 show that section inertia controls this tradeoff. These figures plot moment versus  $I/I_{\rm O}$  for both articulated and rigid rotor systems. With increased I, an increased moment results for both blades. Also shown are effective  $I/I_{\rm O}$  values for blades of other stiffness tapers.

Presented in Tables 2. 11 and 2. 12 is a numerical evaluation of the stiffness-curvature tradeoff for both rigid and articulated systems. For the articulated blade with tapered stiffness, note that the value of I at the critical blade station governs the resulting vibratory moment. Here, both tapered and inverse-tapered blades have the same curvature at the critical station. Yet, vibratory moments are highest for the inverse taper with an increased I of 41% at the critical station.

TABLE 2.11
EVALUATION OF BLADE STIFFNESS
CURVATURE TRADEOFF - ARTICULATED ROTOR

Case	$M_{V}$	I <sub>crit</sub>	I / I <sub>st</sub>	M <sub>v</sub> / M <sub>vst</sub>	y / y <sub>st</sub>
	19939.	5. 80	1.0	1.0	1.0
2	32451.	11.60	2.0	1.62	. 810
2	12272.	2.90	. 5	. 615	1. 23
2	22000	7. 26	1. 25	1.10	. 88
	24913	8. 20	1.41	1. 25	. 886

TABLE 2.12
EVALUATION OF BLADE STIFFNESS
CURVATURE TRADEOFF - RIGID ROTOR

Case	M <sub>v</sub>	l <sub>crit</sub>	I / I <sub>st</sub>	M <sub>v</sub> / M <sub>vst</sub>	ÿ/ÿ <sub>st</sub>
2	61000	10.00	1.0	1.0	1.0
2	86500	20.00	2. 0	1.415	. 7075
1	40500	5.00	. 5	. 665	1.330
2	82570	20.00	2. 0	1.35	. 675
	47000	5.00	.5	. 77	1.54

## V=150 KNOTS G.W.= 33,000-LB. A=185 RPM ARTICULATED ROTOR

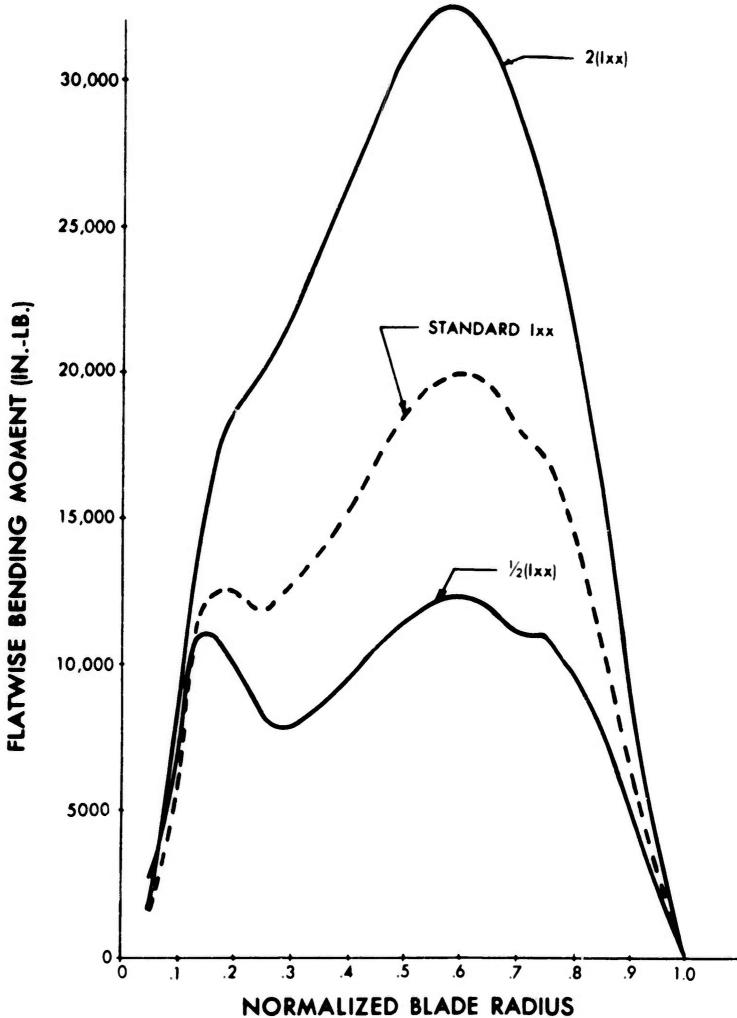


FIGURE 9.1 EFFECT OF VARIABLE FLATWISE STIFFNESS ON BENDING MOMENT

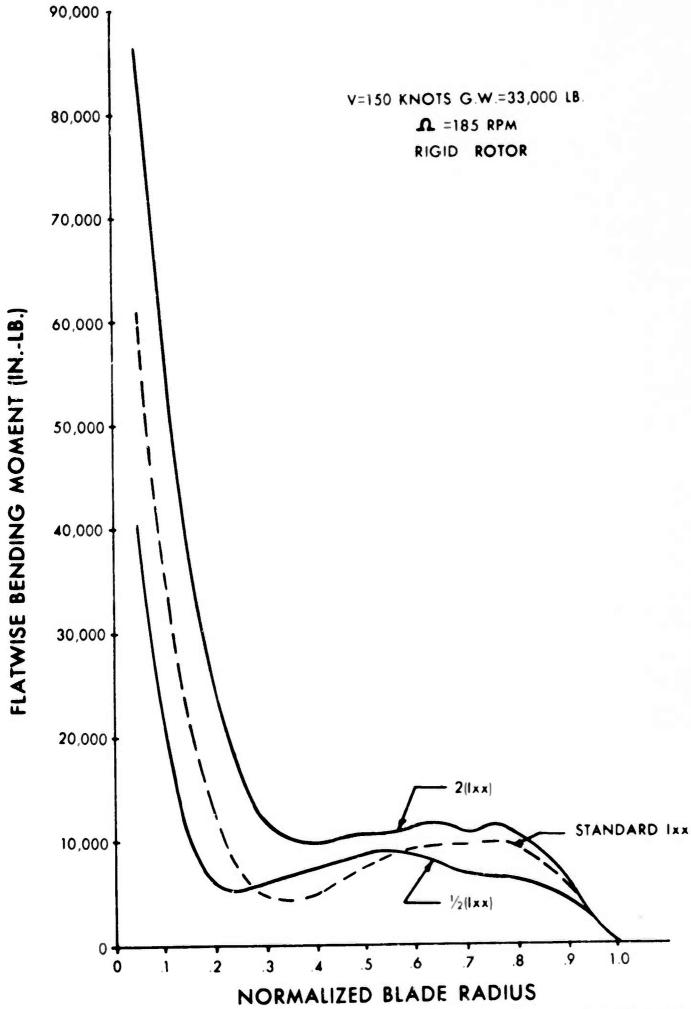


FIGURE 9.2 EFFECT OF VARIABLE FLATWISE STIFFNESS

ON BENDING MOMENT

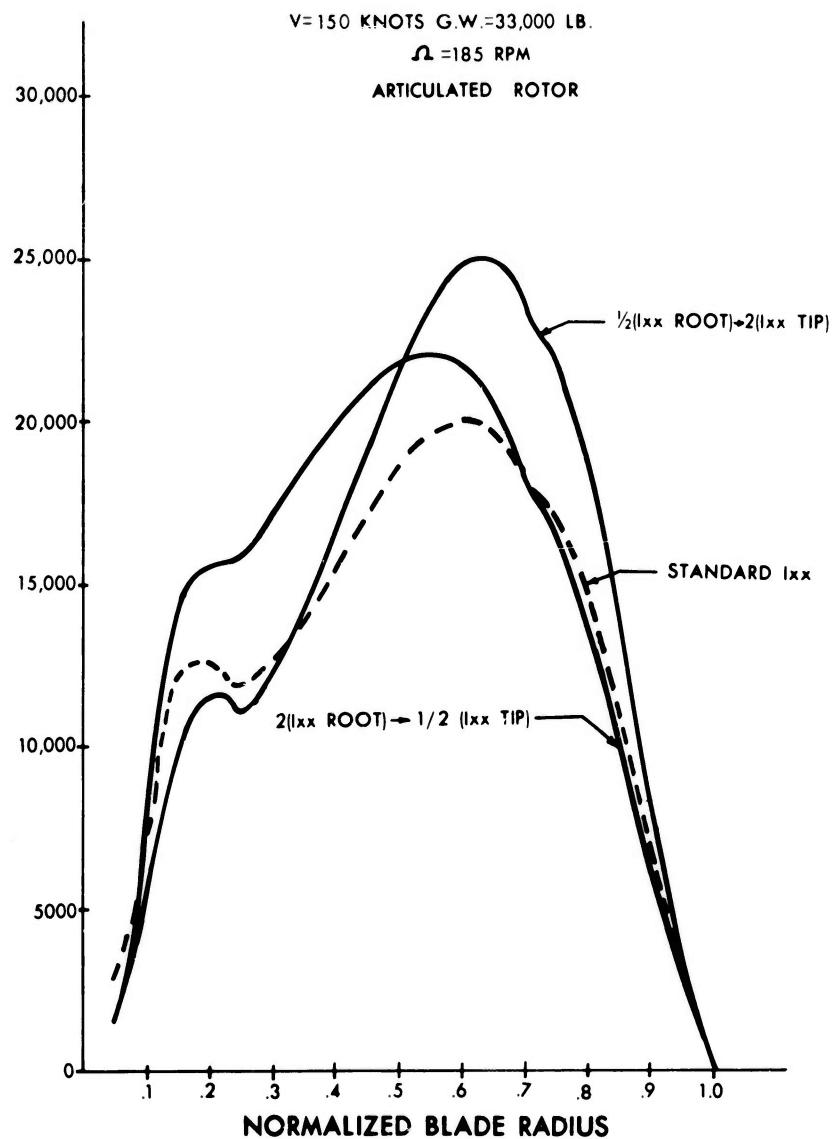


FIGURE 9.3 EFFECT OF VARIABLE FLATWISE STIFFNESS
ON BENDING MOMENT

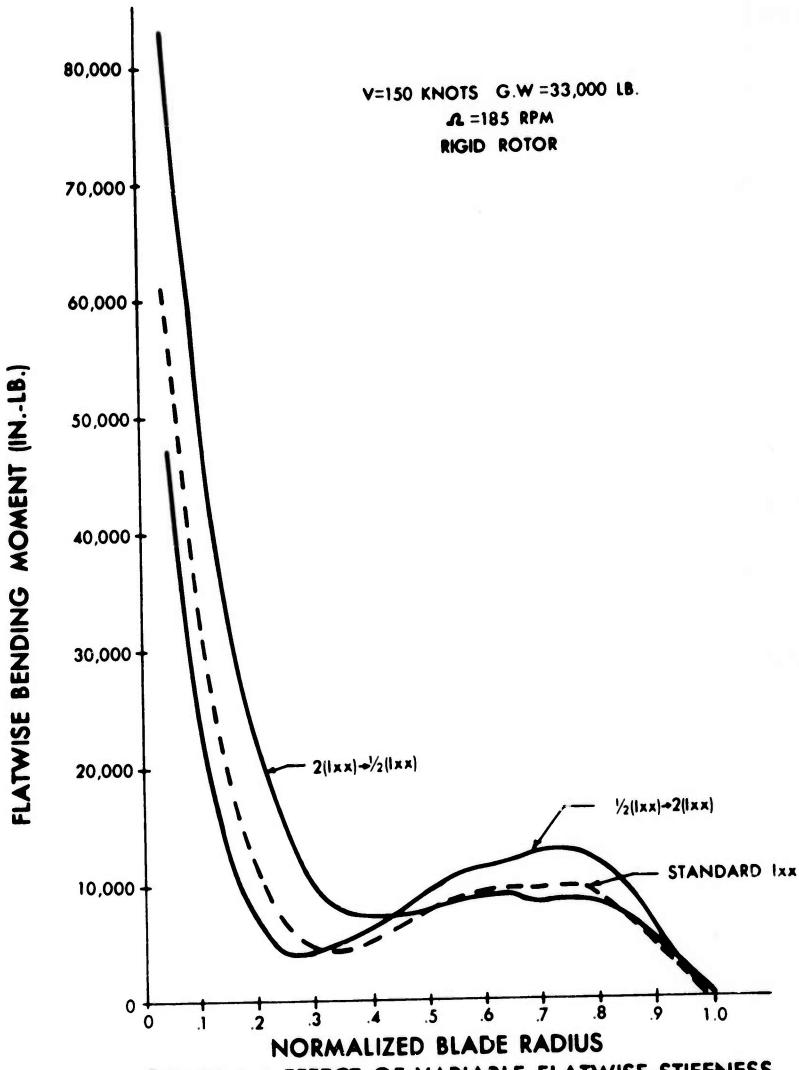


FIGURE 9.4 EFFECT OF VARIABLE FLATWISE STIFFNESS
ON BENDING MOMENT

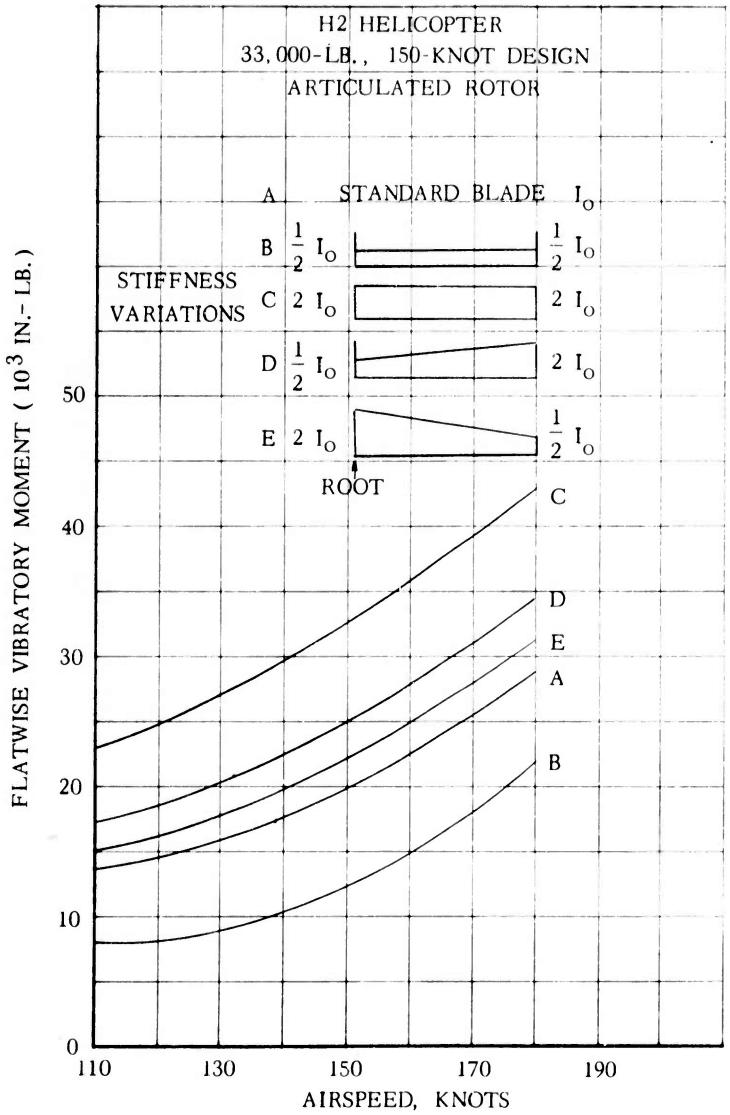


FIG. 9.5 CHANGE IN BENDING MOMENT WITH STIFFNESS VARIATION

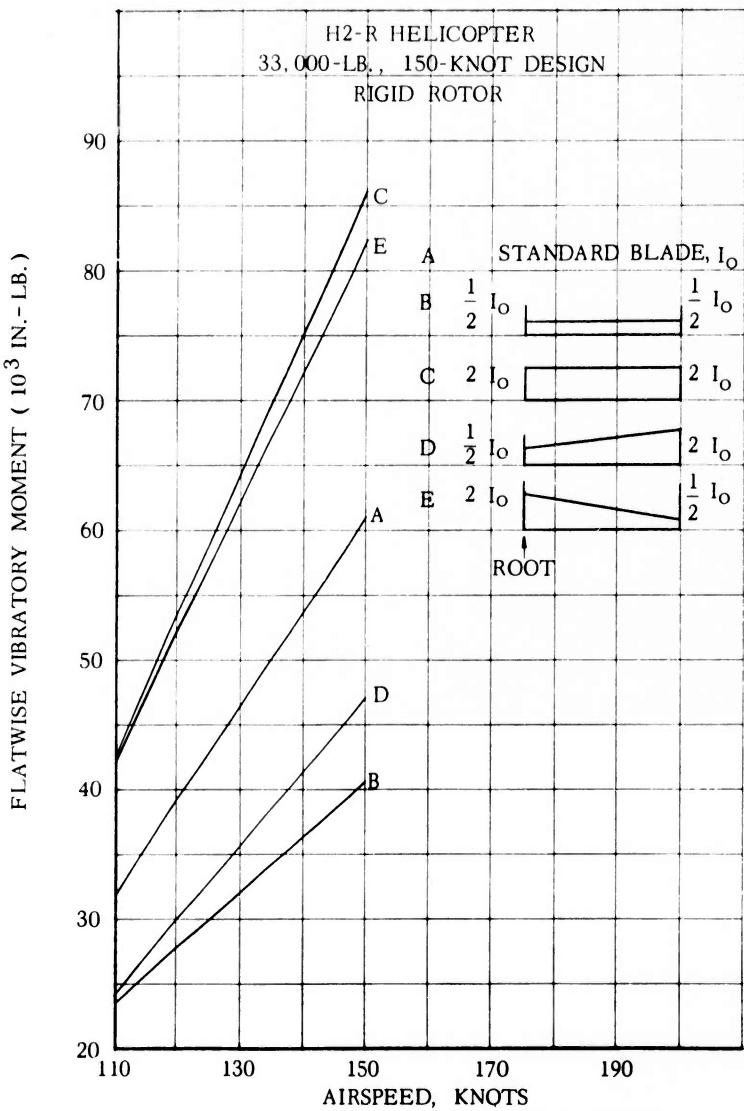


FIG. 9.6 CHANGE IN BENDING MOMENT WITH STIFFNESS VARIATION

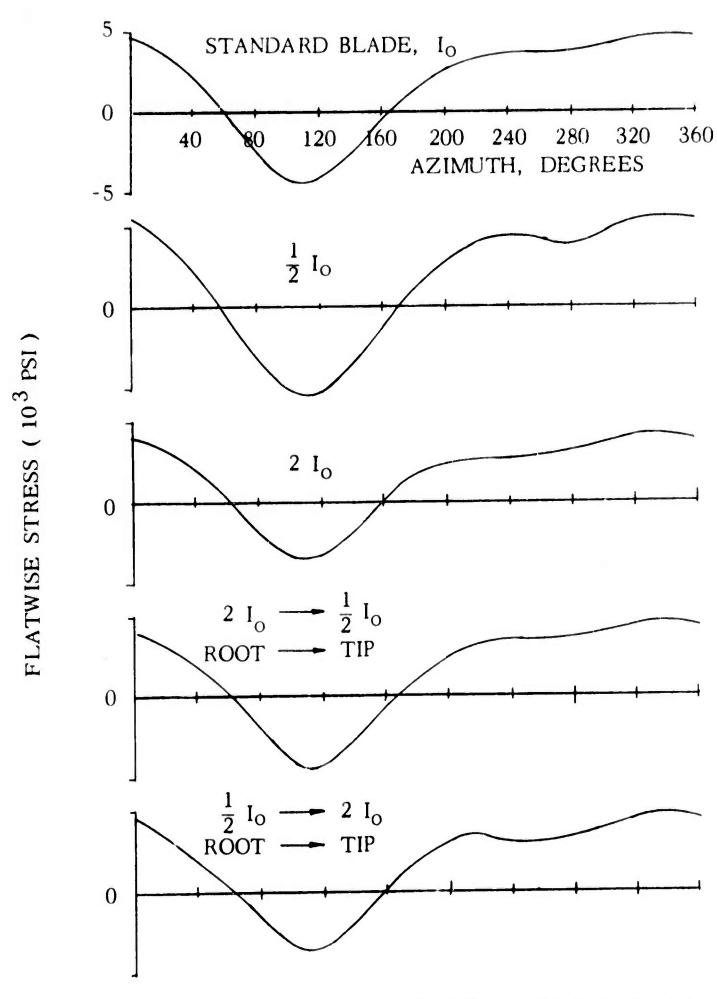


FIG. 9.7 CHANGE IN FLATWISE STRESS WITH AZIMUTH FOR FIVE STIFFNESS VARIATIONS

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## 10. BLADE MASS DISTRIBUTION

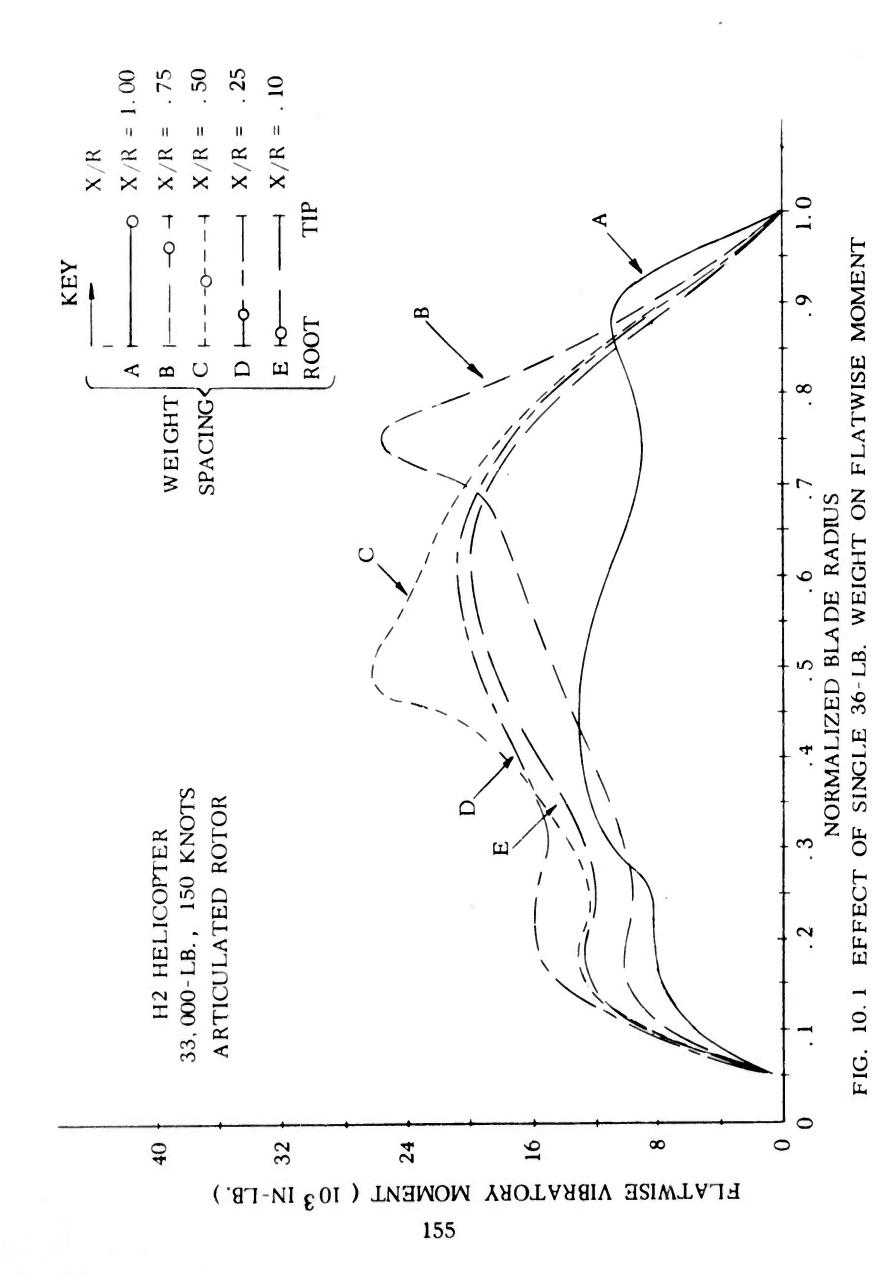
Studies of changes in blade mass distribution were carried out according to the schedule shown in Table 2. 4. Given in Figures 10.1 and 10.2 are effects on flatwise vibratory moments for the 33,000-pound helicopter by separately introducing a concentrated 36-pound weight at five radial locations along the blade. Radial moment envelopes for the five positions for an articulated blade are presented in Figure 10.1. The standard unweighted blade (not shown) had a maximum vibratory moment of 20,000 in. -lb. Given in Figure 10. 3 is a plot of maximum vibratory moment versus blade weight location. Results indicate (1) a significant reduction in vibratory moments (34%) by introducing a weight at the blade tip, and (2) an increase in vibratory moment (max. 38% with weight at r/R = .63) by locating a concentrated weight inboard of 90% radius. Effect on flatwise and edgewise maximum moments by varying the amount of weight added to the blade tip is given by curves shown to the right of Figure 10.4. Here, vibratory moment reduction is greatest with the first 10 pounds added; it then levels off in the 30-to-40-pound region.

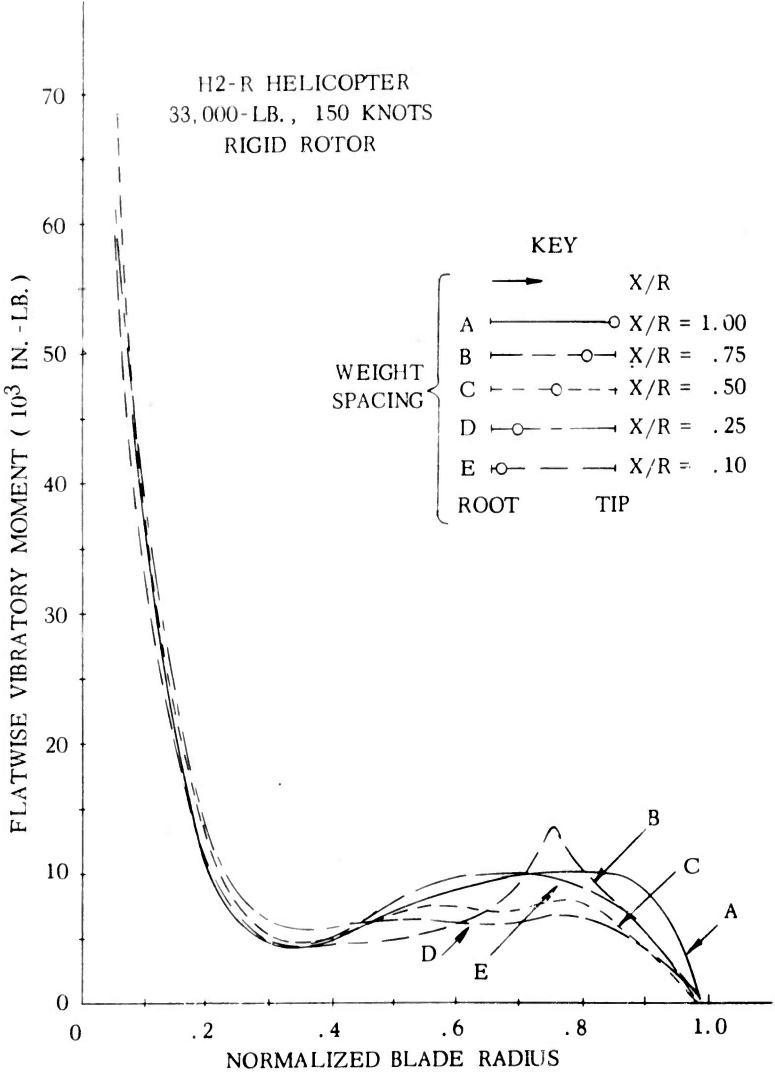
Effects of added concentrated weights for rigid blade moments are plotted in Figure 10.2. In this case the root region was most critical. Maximum vibratory moment for the standard blade (not shown) was 61,000 in. -lb. Figure 10.5 shows the trend in maximum vibratory moment with change in location of the concentrated weight. Here, the tip weight again produced a significant reduction (25%), but weights inboard resulted in an increase (max. of 15% with weight at r/R = .40). The lefthand plots of Figure 10. 4 present results of varying tip weight on rigid blade moments. Flatwise moment reduction follows the same trend as the articulated system. The sharp continuous reduction shown for edgewise moments is attributed to detuning the first edgewise mode. The rigid blade in this case (aspect ratio = 18) was designed for  $\omega = .65 \Omega$ . Added weight brings this mode further below one-per-rev. Were a stiff inplane design used, the addition of tip weight would have the opposite effect. Edgewise moments would increase, for the first edgewise mode would be reduced from 1.4  $\Omega$  in the direction of one-per-rev.

Radial moment envelopes for various single weight locations for a six-bladed teetering rotor are given in Figure 10. 6. For this rotor system, results show moment increases at all points of location of concentrated weight.

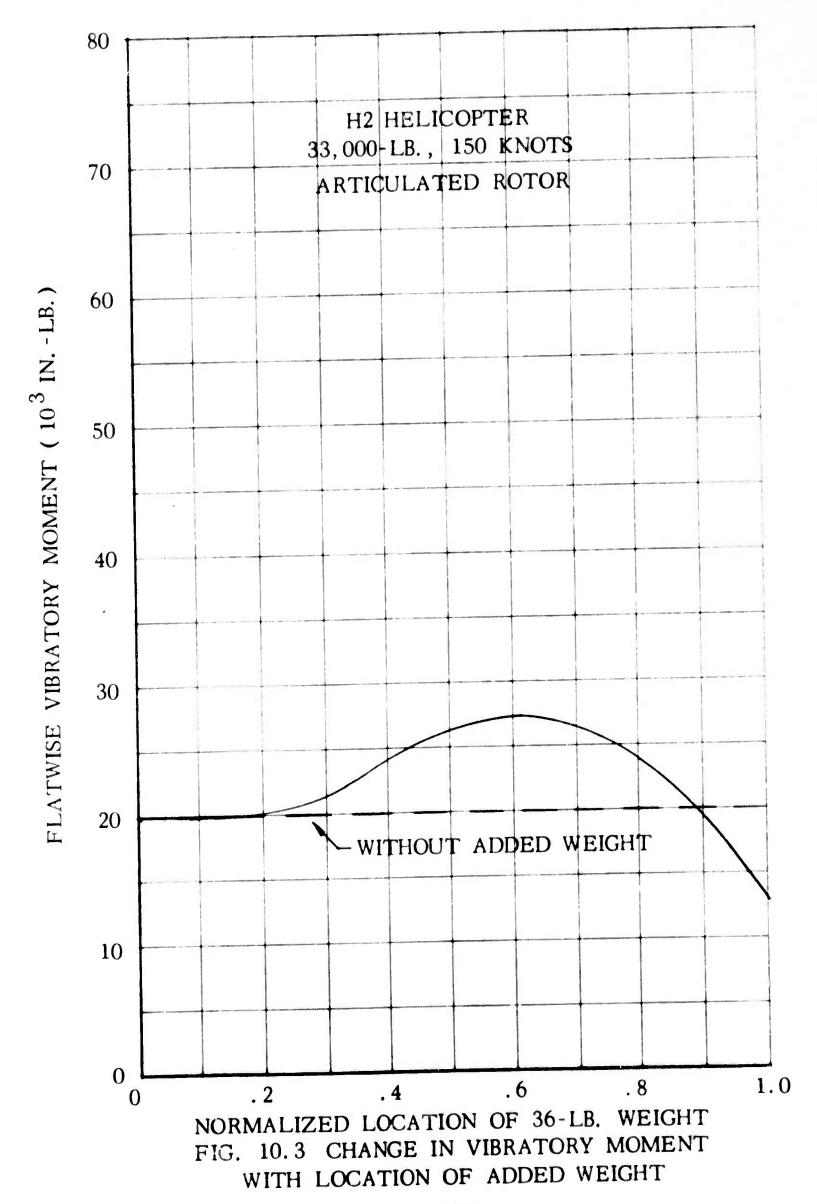
Effects of various combinations of two 18-pound weights are shown in Figures 10. 8, 10. 9, and 10. 10 for articulated, rigid, and six-blade teetering rotors respectively. Lowest moments were noted for the combination that included a concentrated tip weight with the second weight well inboard where single weight studies showed only a small moment increase.

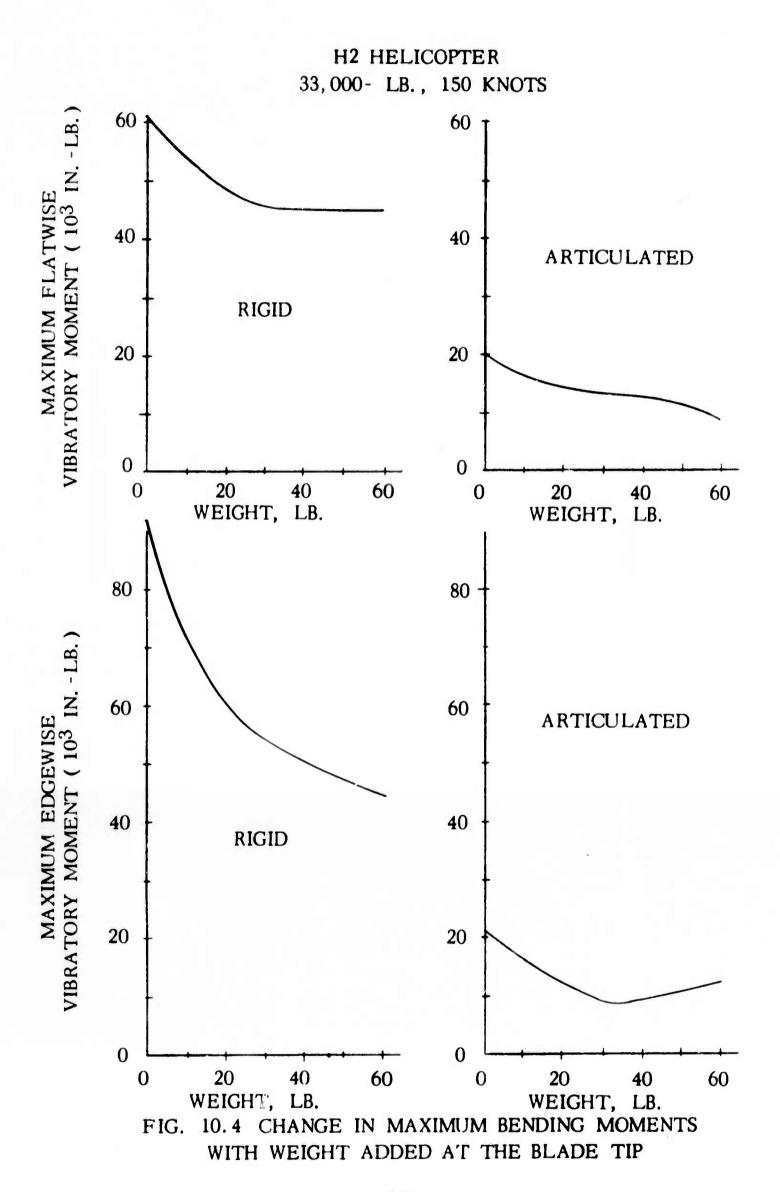
Shown by Figures 10.11, 10.12, and 10.13 are results from tapering blade mass distribution for the three rotor systems as specified by Table 2.4. Increasing mass with rotor radius was found to reduce blade vibratory moments, whereas decreasing mass with rotor radius gave increased vibratory moments. Similar to the findings with concentrated weights, these results show reduced moments as weight is added at the blade tip.

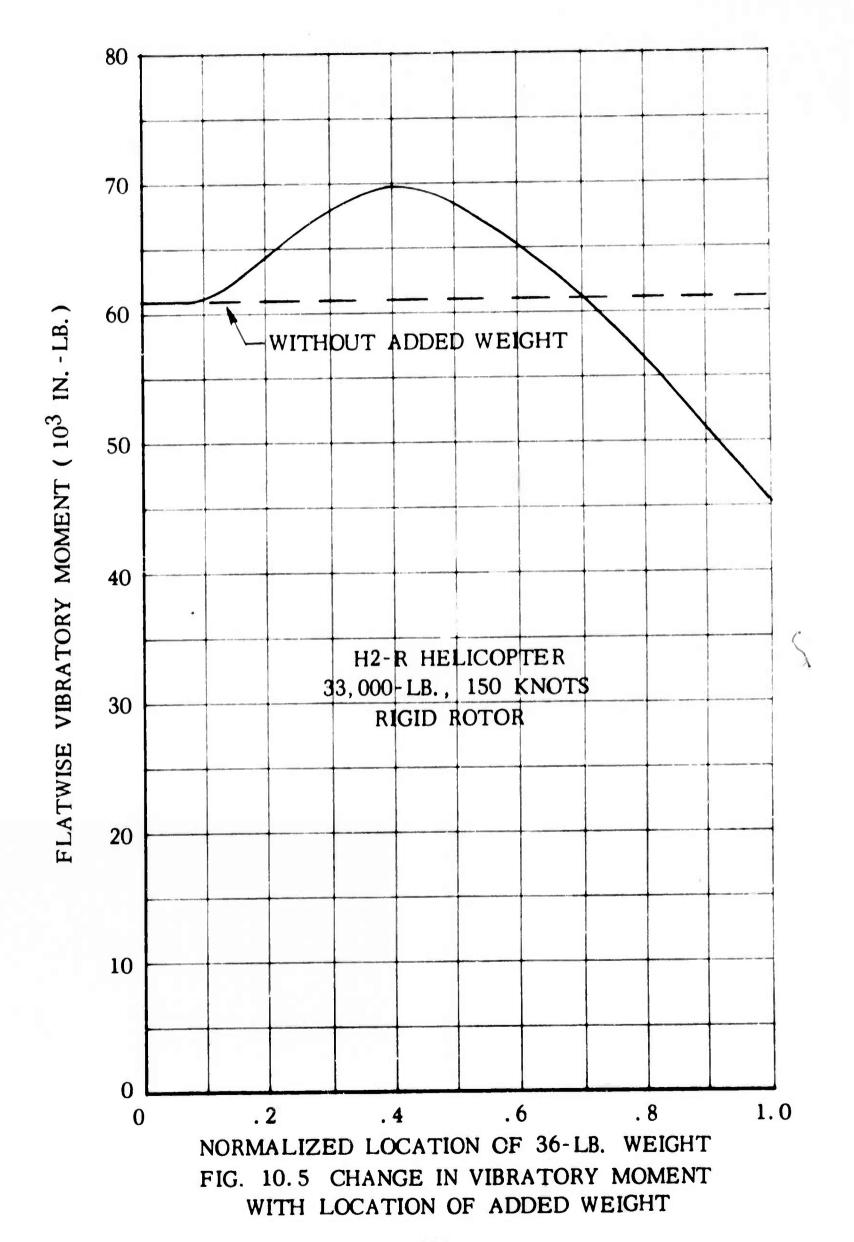


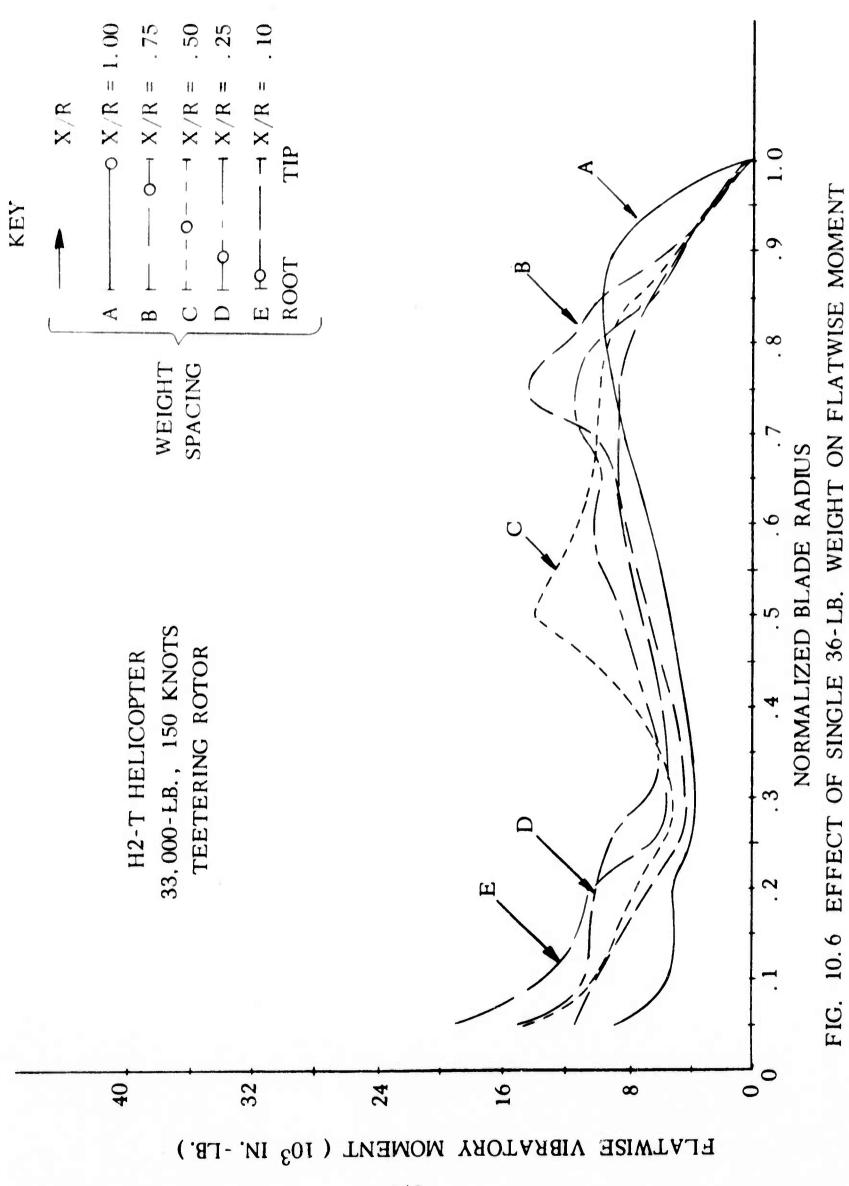


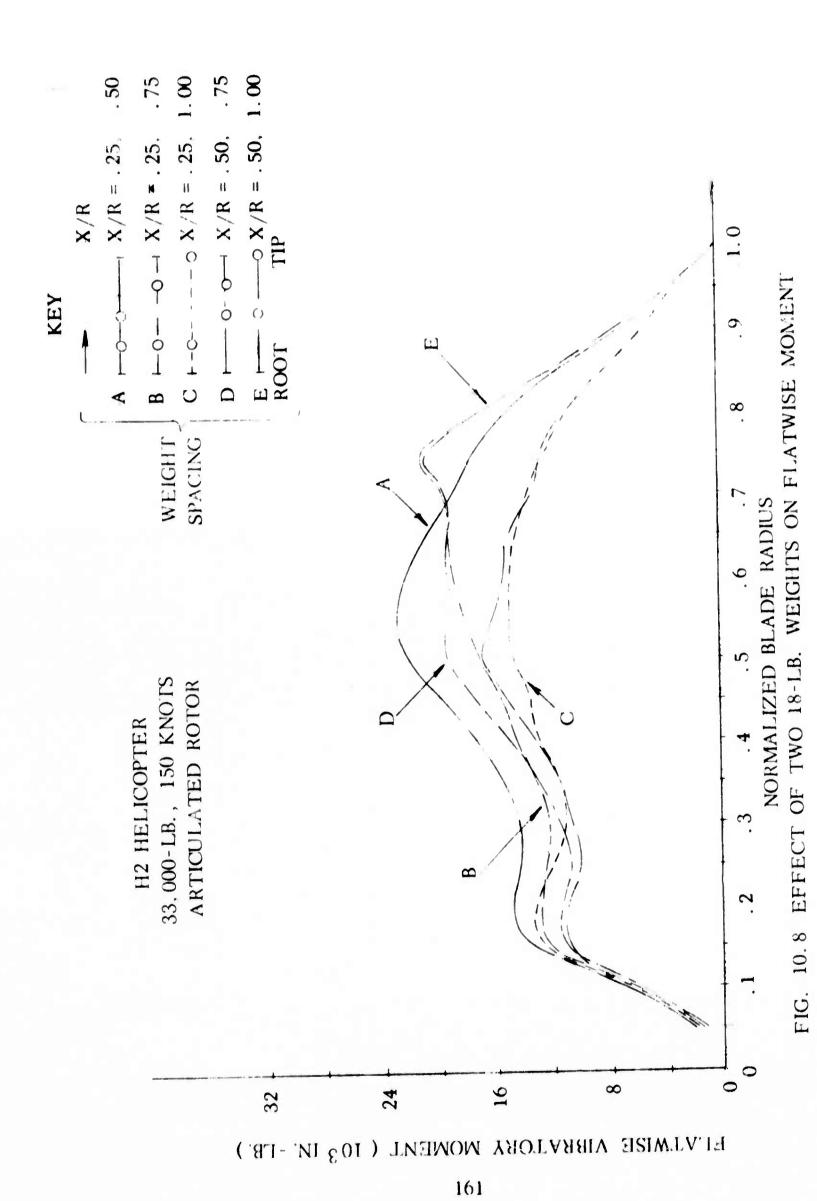
NORMALIZED BLADE RADIUS
FIG. 10.2 EFFECT OF SINGLE 36-LB. WEIGHT
ON FLATWISE MOMENT











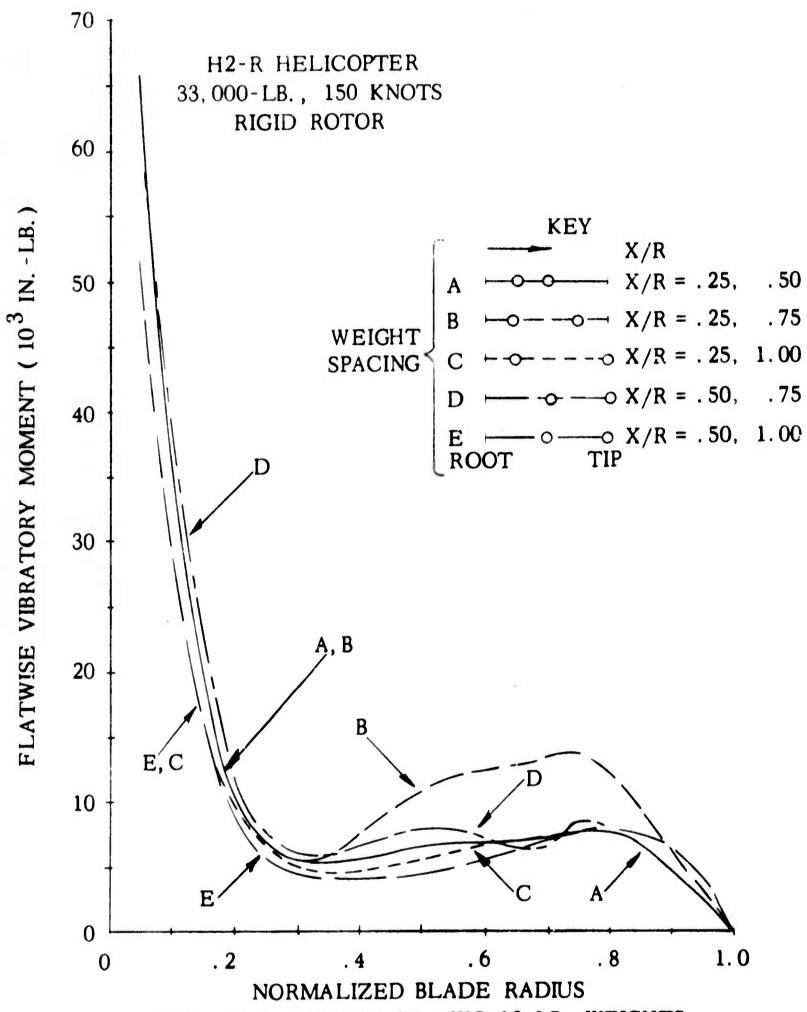
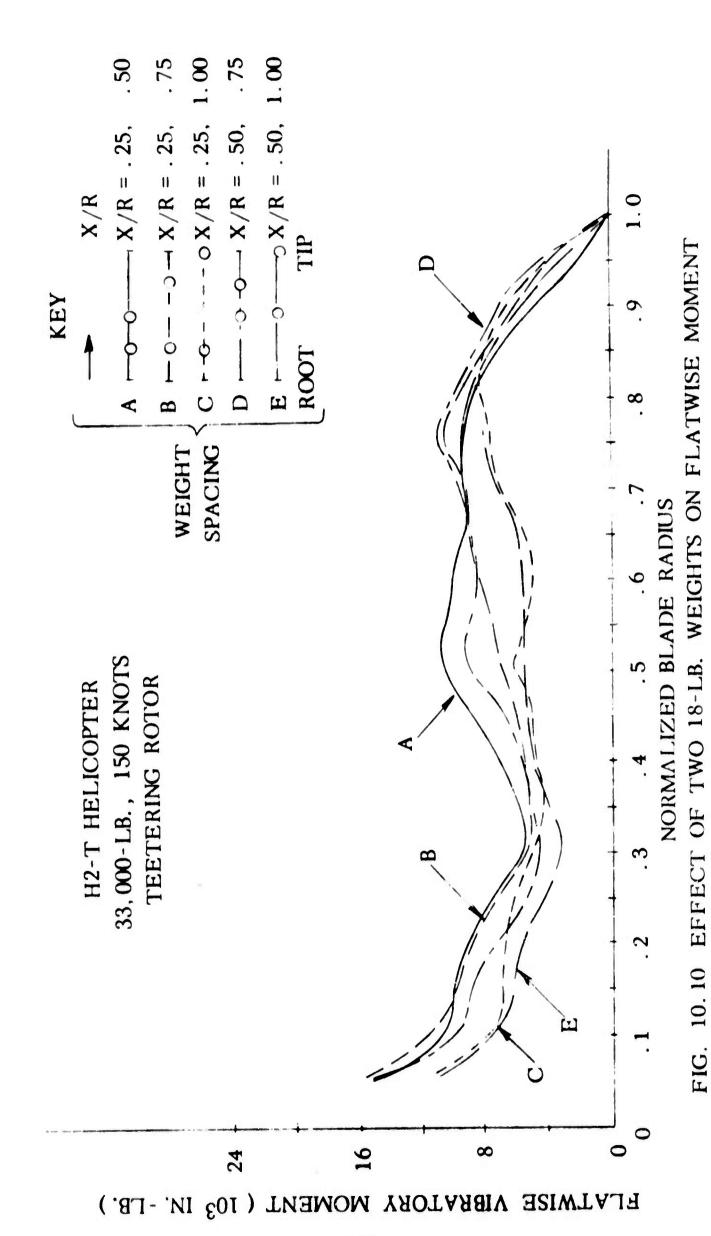
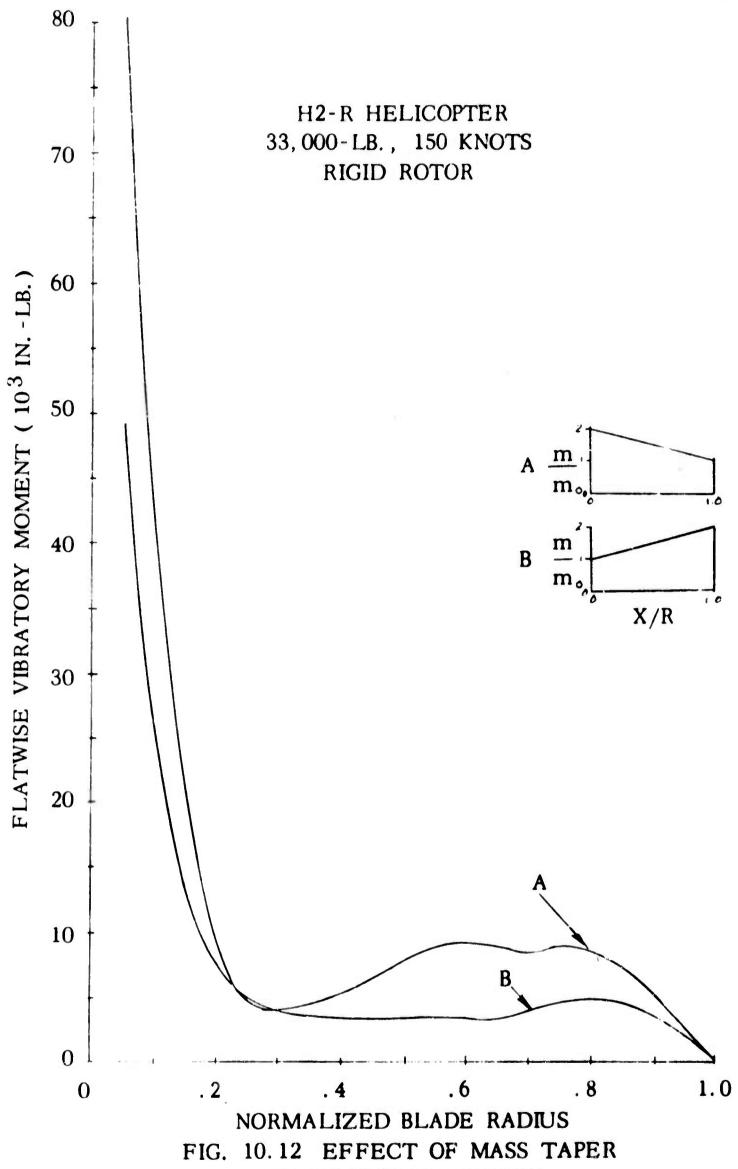


FIG. 10.9 EFFECT OF TWO 18-LB. WEIGHTS
ON FLATWISE MOMENT



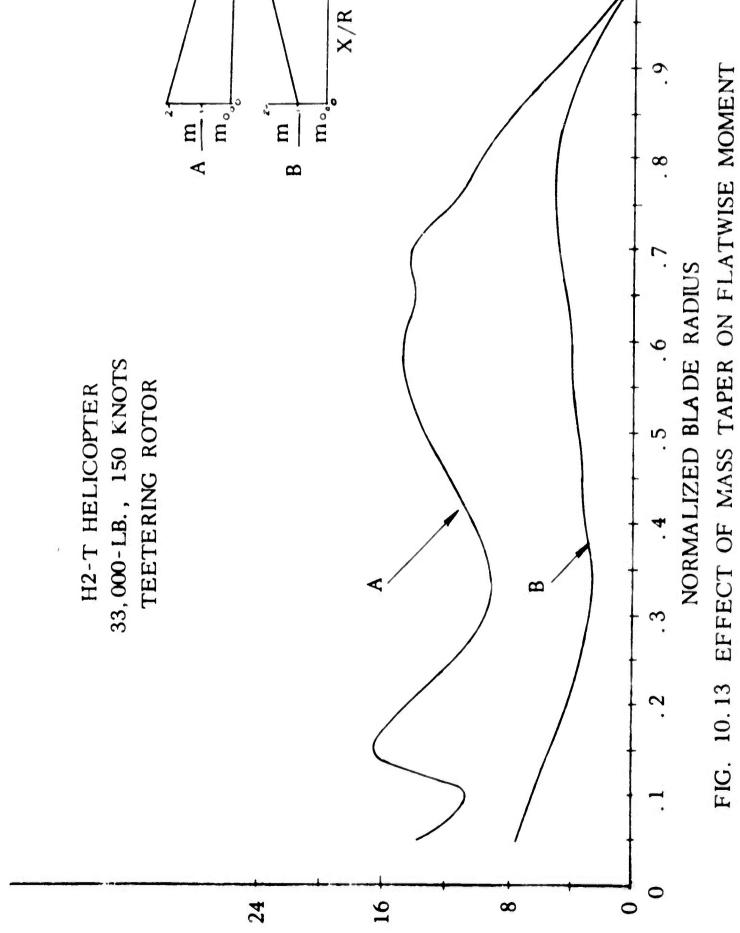
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FI.ATWISE VIBRATORY MOMENT (  $10^3$  IV. - LB. )



ON FLATWISE MOMENT

FLATWISE VIBRATORY MOMENT (  $10^3$  IN. - LB. )



# 11. BLADE RESTRAINT VARIATIONS

# A. ROTOR HEAD IMPEDANCE

An important feature of the Sikorsky blade dynamic analysis program is that it provides for blade-fuselage coupling. This effect is generally ignored in most blade dynamic studies. Experience at Sikorsky Aircraft indicates that blade-fuselage coupling does not significantly alter one-per-rev blade vibratory stresses, which usually govern blade design, but coupling effects may be important when considering vibrations of the fuselage and higher mode response of the blades.

In the blade-fuselage coupling relationships, the dynamics of the flexible blade are "married" to dynamics of the fuselage by matching blade impedance to fuselage impedance at the rotor head. The "heart" of this analysis consists of two coordinate transformations, one relating forces in the rotating system to forces in the fixed system and the other relating angular and linear displacements in the rotating system to the fixed system. For an n-bladed helicopter, results of the calculation give the n/rev. vertical and coupled-lateral-torsion fuselage response at a particular airspeed. Also obtained is the n-1, n, and n+1/rev. flatwise-edgewise blade response for that airspeed.

Blade-fuselage coupling is shown in Figure 11.1. A flow chart relating blade fuselage coupling to aerodynamic and blade dynamic analysis is given in Figure 11.2. In applying blade-fuselage coupling relationships to a blade dynamic analysis, a fuselage analysis is not necessarily required. The basic equations can be used for studies of the effect of blade root impedance on blade dynamics.

The following matrix of hub motion was chosen as a reasonable set for a standard. The zeros are due to decoupling of the vertical from the lateral torsion response. Also, since the numbers are real, no fuselage damping has been included.

Г -	1	Г					7	r 7
x		1093. 85	0	-217. 25	0	67. 48	0	Sx
Y		0 -	532.07	0	20.02	0	87	Sy
z		-217. 25	0	-103. 29	0	-6. 60	0	Sz
$\phi_{\rm F}$	=	0	20.02	0	3. 79	0	01	M <sub>XX</sub>
$\theta_{ extbf{F}}$		67.48	0	-6. 60	0	5. 17	0	M <sub>yy</sub>
$\psi_{ m F}$		0	87	0	01	0	01	Mzz
L_								

# \* All values to be multiplied by $10^{-8}$

Seven cases of hub impedance were considered in the investigation. These were the standard case, described previously, a rigid hub case, and cases in which the basic hub admittance matrix was multiplied by factors of  $10^{-2}$ ,  $10^{-1}$ ,  $10^{1}$ ,  $10^{2}$ , and  $10^{3}$ . Shown in Figures (11.3 through (11.8 are plots of sine and cosine components of shear versus impedance for the 5, 6 and 7/rev. frequencies. As admittance is increased or impedance is decreased, shears are noted to approach zero. This is expected, for the blade approaches the free-free condition.

Flatwise and edgewise vibratory components of root motion for the minimum hub impedance ranged from  $7 \times 10^{-5}$  inches to  $8 \times 10^{-3}$  inches, and reflected a substantial change in blade mode shape from the rigid hub condition. For this change in mode shape, there would be a corresponding change in blade natural frequency. Results indicate that blade fuse-lage coupling may have to be taken into account in predicting

higher harmonic blade and associated fuselage response.

# B. BOUNDARY CONDITIONS

Table 2.5 summarizes the three variations in blade boundary conditions which were investigated. Here, the blade was taken as (1) articulated flatwise, cantilevered edgewise; (2) cantilevered flatwise, articulated edgewise; and (3) articulated flatwise, articulated edgewise. Variations considered under this part of the study represent limit conditions for the root flexibility study of Section 11-C.

Figure 11. 9 gives the radial distribution of vibratory flatwise bending moment for the three cases considered. As would be expected, the flatwise root moment increases with degree of flatwise restraint. There is zero flatwise moment for the double articulated blade; more root moment with the blade articulated flatwise, cantilevered edgewise; and greatest flatwise root moment for the cantilevered flatwise, articulated edgewise case. Shown in Figure 11. 9a are corresponding radial distributions of edgewise vibratory moment. Here, trends of root vibratory are in proportion to degree of edgewise root restraint.

# C. BLADE ROOT FLEXIBILITY

The schedule followed for varying root flexibility is given by Table 2. 6. Variations were carried out on the H2 helicopter at 150 knots. Results are presented in Figures 11. 10 through 11. 15.

Change in flatwise vibratory moment with change in flatwise root restraint is given in Figure 11. 10. Here, flatwise root restraint was varied from fully articulated to fully cantilevered. Edgewise restraint was kept articulated as flatwise root flexibility varied. Note the change in vibratory moment distribution as stiffness at the root increases. Distributions shown for root flexibilities ranging from 0 to 100,000 in. -lbs. /rad. are typical of articulated blades, with the maximum occurring at about two-thirds blade radius. Root flexibility of one million in. -lbs. /rad. is seen to result in a root moment about equal to the outboard moment. As root flexibility is further increased, we observe an associated increase in root moment and some decrease in moment at the outboard blade stations.

Effects of change in edgewise root flexibility, while holding flatwise articulated, are shown in Figures 11. 12 and 11. 13. Given in Figure 11. 13 are changes in corresponding edgewise moment envelopes, while Figure 11. 12 gives corresponding changes in flatwise moments. The high value of edgewise moment as edgewise restraint becomes infinite is attributed to resonance. That is, the first edgewise mode for the blade considered approaches one-per-rev with cantilever restraint. This is avoided in design of rigid rotor systems by following the inplane tuning criteria as set forth in Section 4. Corresponding changes in flatwise moments with change in edgewise restraint (Figure 11. 12) do not appear to be significant until the restraint approaches 10 million in. -lbs. /rad. Variations shown are due to flatwise-edgewise coupling.

Presented in Figures 11. 14 and 11. 15 are effects on the radial distribution of flatwise and edgewise vibratory moments due to increasing the amount of damping at the lag hinge. For high amounts of damping, trends observed are seen to be similar to results obtained by varying edgewise root restraint.

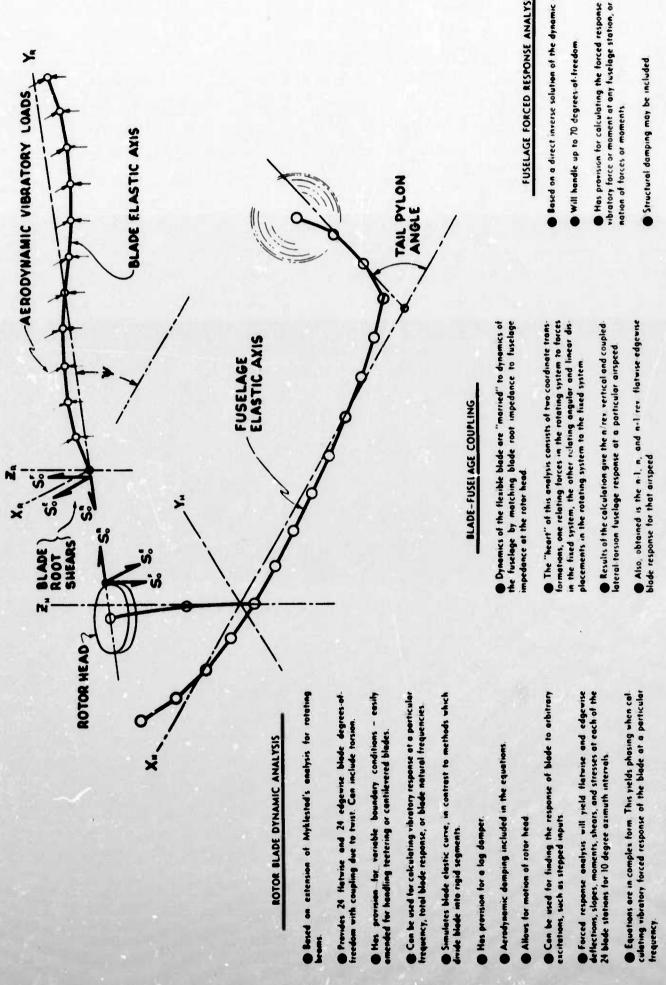
In addition to parametric studies just described, an investigation of root flexibility was carried out on the Lockheed CL-475, prototype rigid rotor helicopter. Proper treatment of blade root flexibility is of prime importance in design of rigid rotor systems. Rigid rotor designers point out that the term "rigid" is a misnomer and that "hingeless" is a preferred definition. In truth, the root region of these blades is far from being a mathematical cantilever. Designed flexibility contributes to a root restraint, which is between a theoretical rigid and hinged condition.

For the Lockheed CL-475 helicopter, effects of root flexibility on calculated vibratory bending moments and stresses are given in Figures 11.16, 11.17, 11.18, and 11.19. Calculations were made at 100 mph. For the first three figures, flatwise root flexibility has been varied, while edgewise restraint is held to a value representative of the actual CL-475 design.

The first plot, Figure 11.16, gives the distribution of flatwise vibratory moments along the blade for an articulated version of the CL-475. Observe that the curve is again typical of articulated blades in that the maximum vibratory moment

occurs at about two-thirds blade radius. Maximum value is ±2100 inch-pounds. The second plot, Figure 11.17, shows corresponding flatwise vibratory moments for a theoretically rigid root restraint. In this case, the outboard blade moment is seen to increase to ±2700 inch-pounds; while at the root, moments reach a value in excess of ±8000 inch-pounds. Finally, shown in Figure 11.18 are calculated moments for a blade with selected flatwise root restraint. For thid condition, outboard blade moments are reduced to ±650 inch-pounds, while root vibratory moments increase to about double the maximum level for the articulated blade. Toward the root, more blade area is required to carry centrifugal loads, so a section modulus can be selected for a semirigid blade that will yield vibratory stress levels comparable to those of an articulated design.

Sensitivity of edgewise stresses to proper tuning is illustrated by Figure 11.19. Lockheed recommends a frequency ratio of 1.4  $\Omega$ , which is apparent from the plot, where vibratory stresses are seen to become excessively large as the first edgewise mode of the blade approaches one-per-rev. Results given are for a neutral c. g. fuselage trim condition. Center-of-gravity shifts can increase edgewise stresses due to increased first harmonic bending and associated Coriolis forces.



- Dynamics of the flexible blade are "married" to dynamics of the fuselage by matching blade root impedance to fuselage impedance at the rotor head.
- The "keart" of this analysis consists of two coordinate transformations, one relating forces in the rotating system to forces in the fixed system, the other relating angular and linear displacements in the rotating system to the fixed system
- Results of the calculation give the nirev vertical and coupled-lateral torsion fuseloge response at a particular airspeed.
- Also, obtained is the n.l. n, and n.l. rev. flatwise edgewise blade response for that airspeed

# FUSELAGE FORCED RESPONSE ANALYSIS

- Based on a direct inverse solution of the dynamic matrix
- Will handle up to 70 degrees of freedom
- Has provision for calculating the forced response due to any vibratory force or moment at any fuselage station, or any combination of forces or moments
- Structural damping may be included

# FIGURE 11.1 COUPLED BLADE-FUSELAGE DYNAMIC ANALYSIS

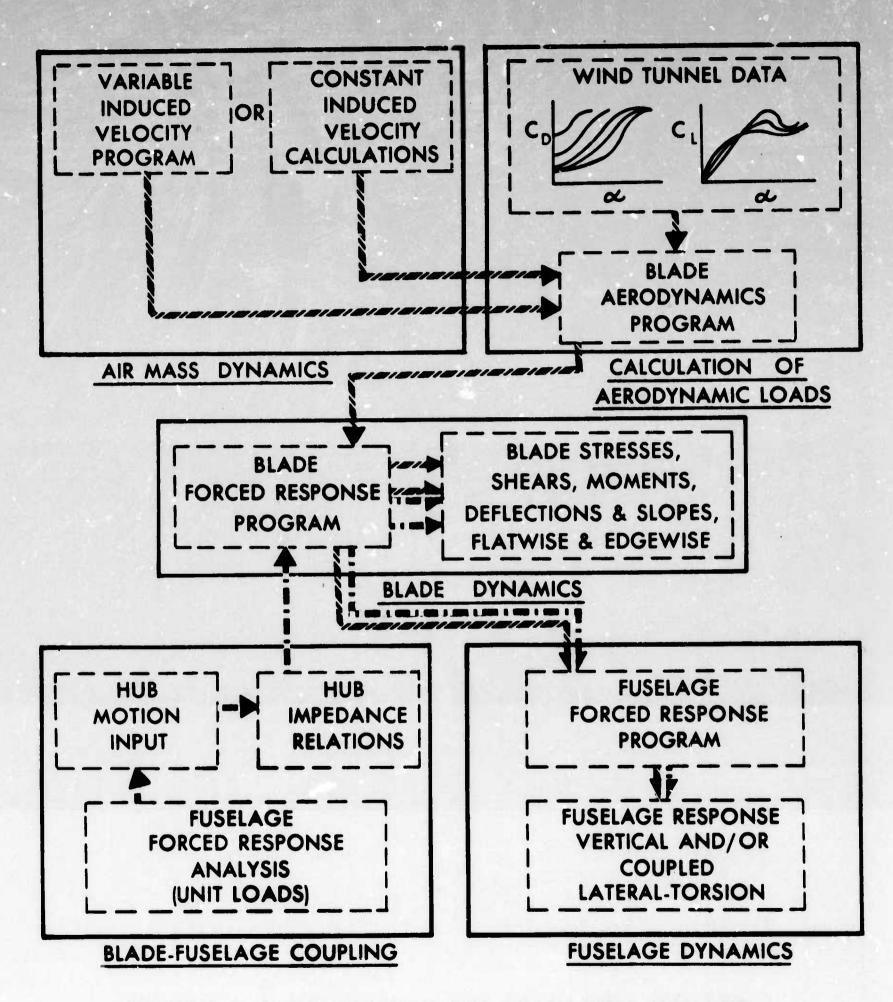


FIGURE 11.2 BLOCK DIAGRAM FOR AEROELASTIC ANALYSIS

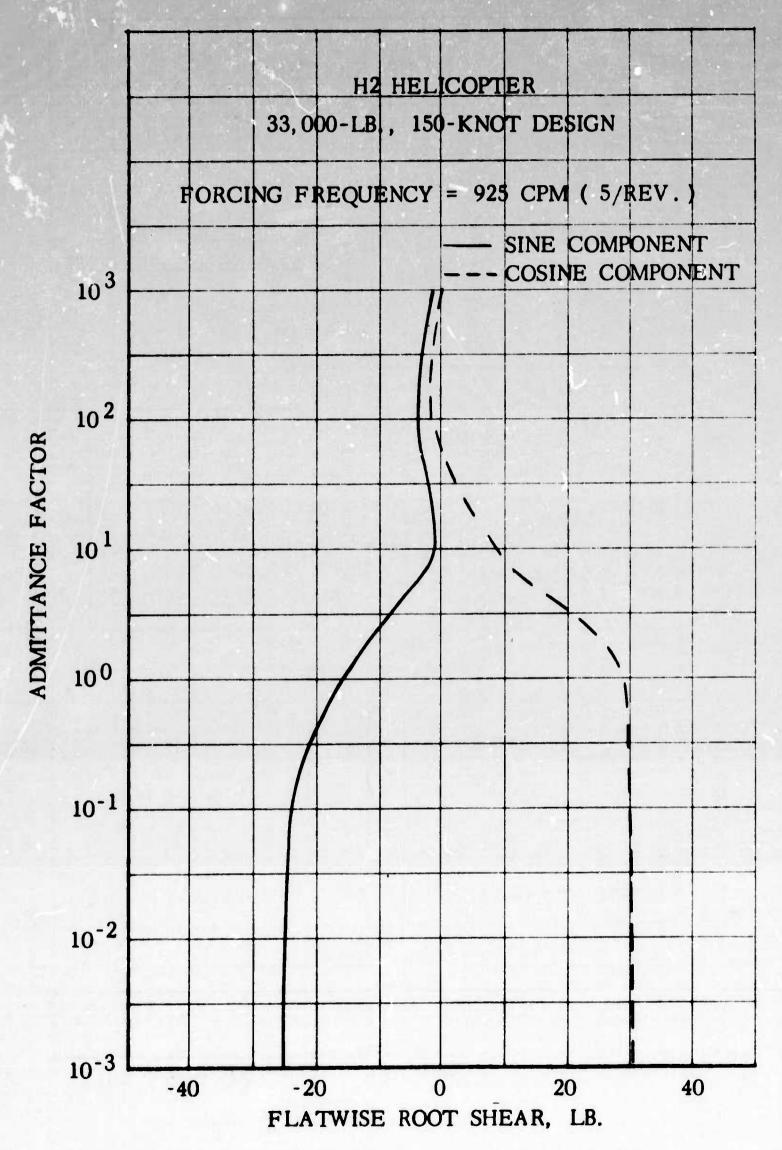
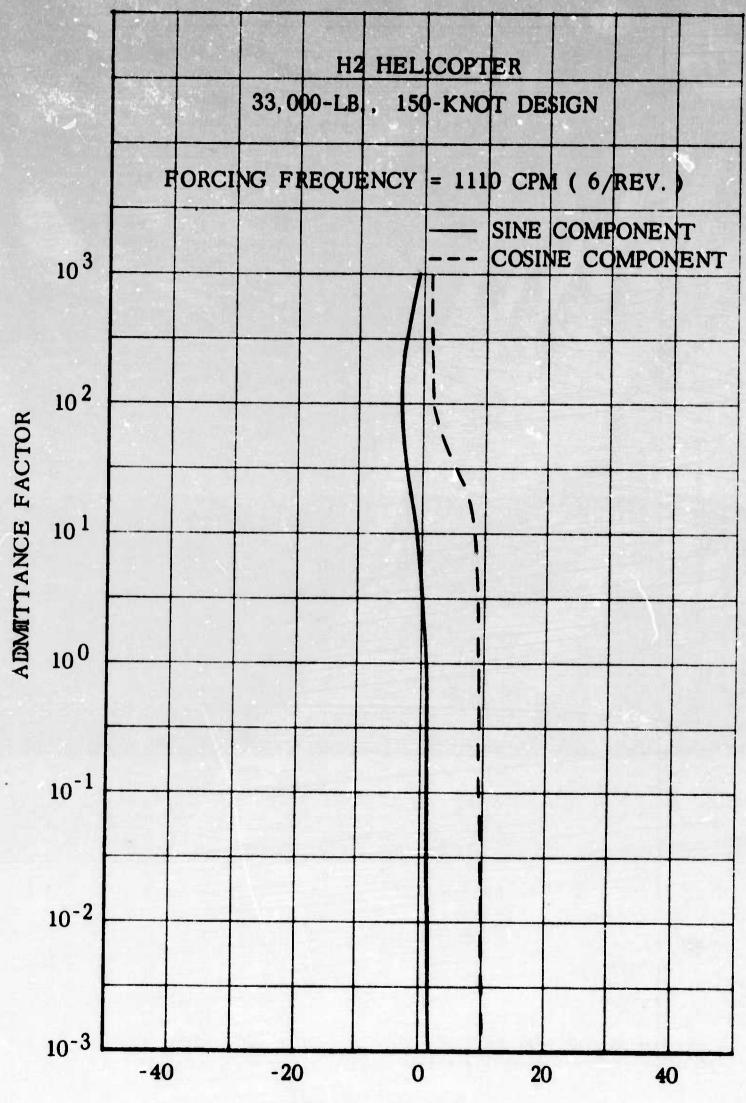


FIG. 11.3 EFFECT OF ROTOR HUB MOTION ON BLADE ROOT FLATWISE SHEAR 174



19,1

FLATWISE ROOT SHEAR, LB.

FIG. 11.4 EFFECT OF ROTOR HUB MOTION ON BLADE ROOT FLATWISE SHEAR

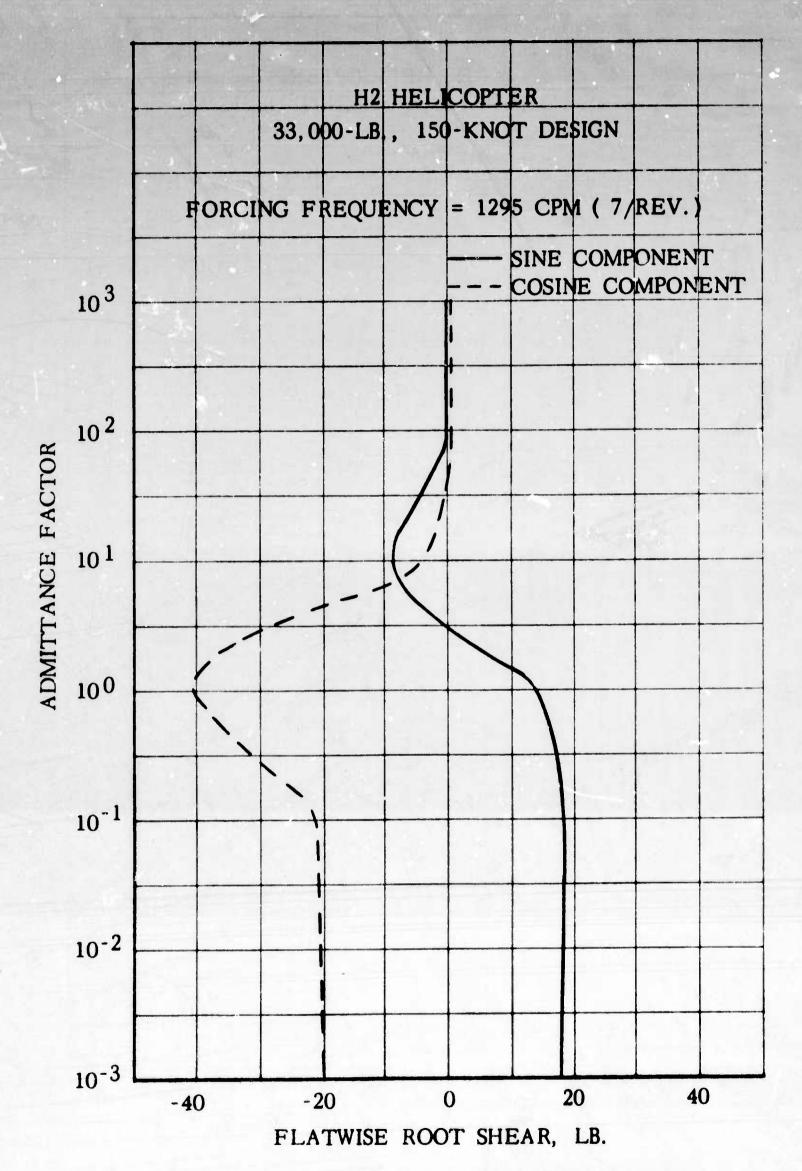
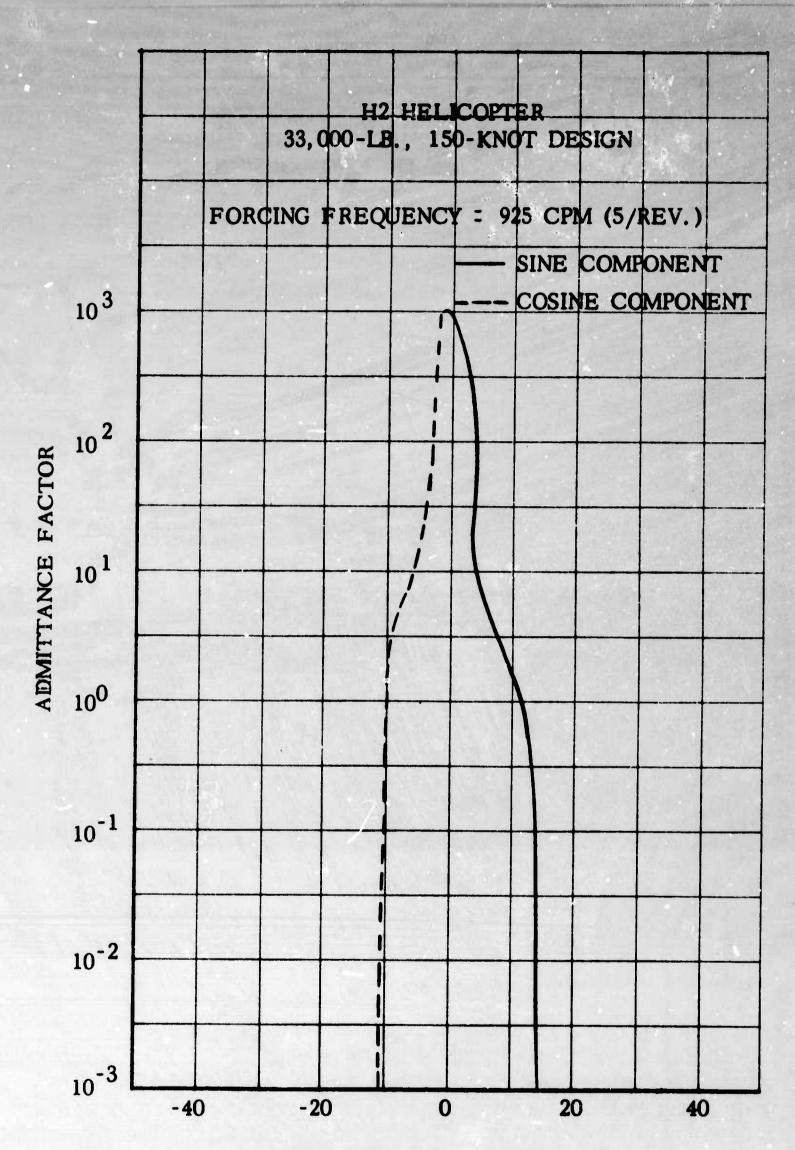
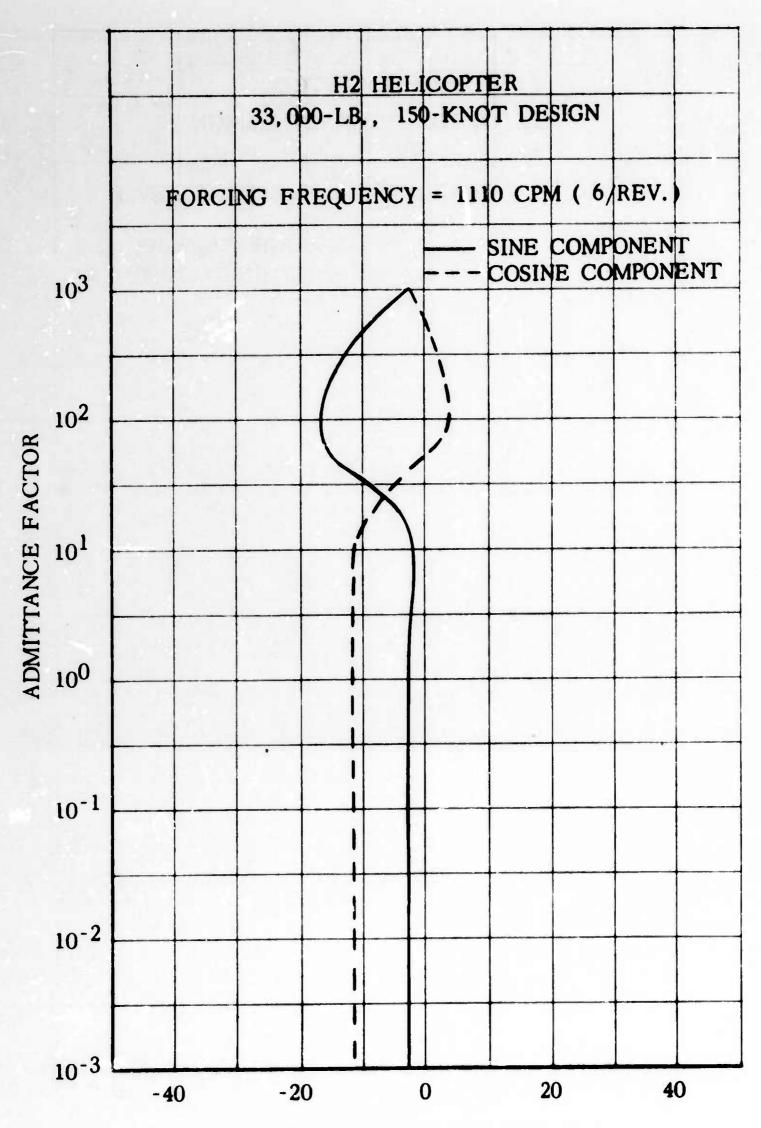


FIG. 11.5 EFFECT OF ROTOR HUB MOTION ON BLADE ROOT FLATWISE SHEAR



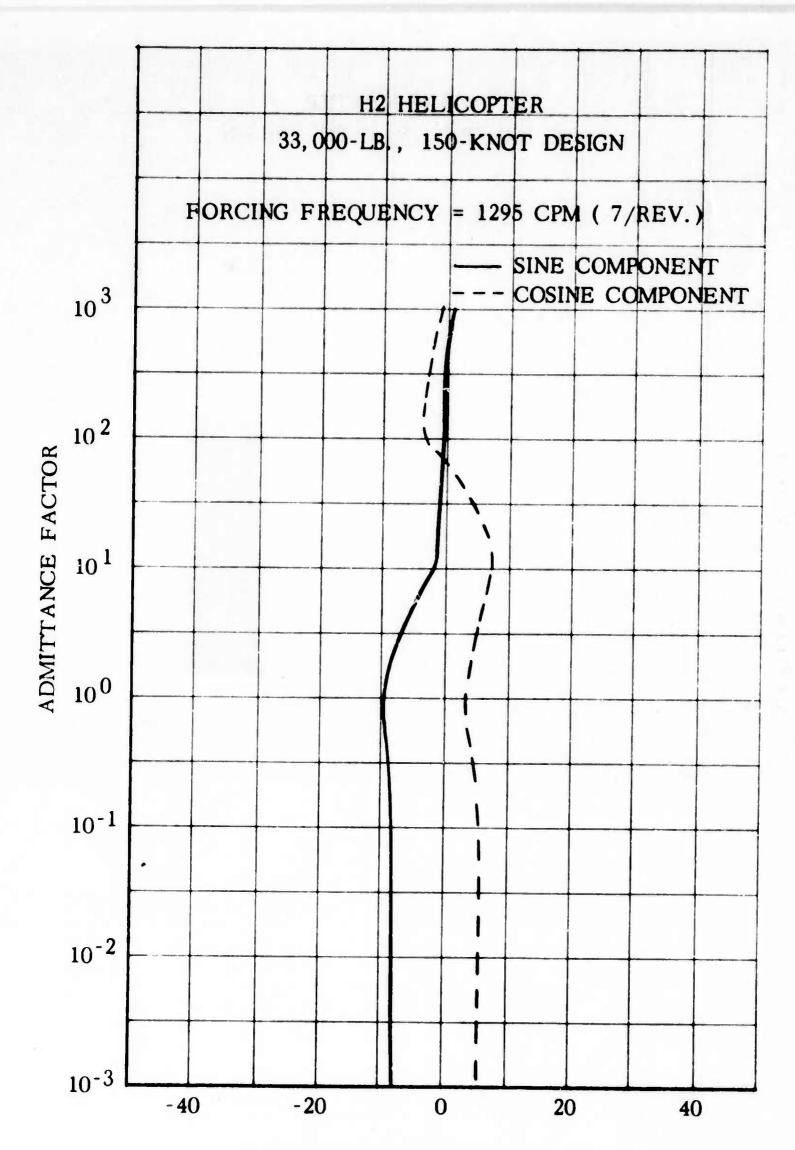
EDGEWISE ROOT SHEAR, LB.

FIG. \$1.6 EFFECT OF ROTOR HUB MOTION ON BLADE ROOT EDGEWISE SHEAR



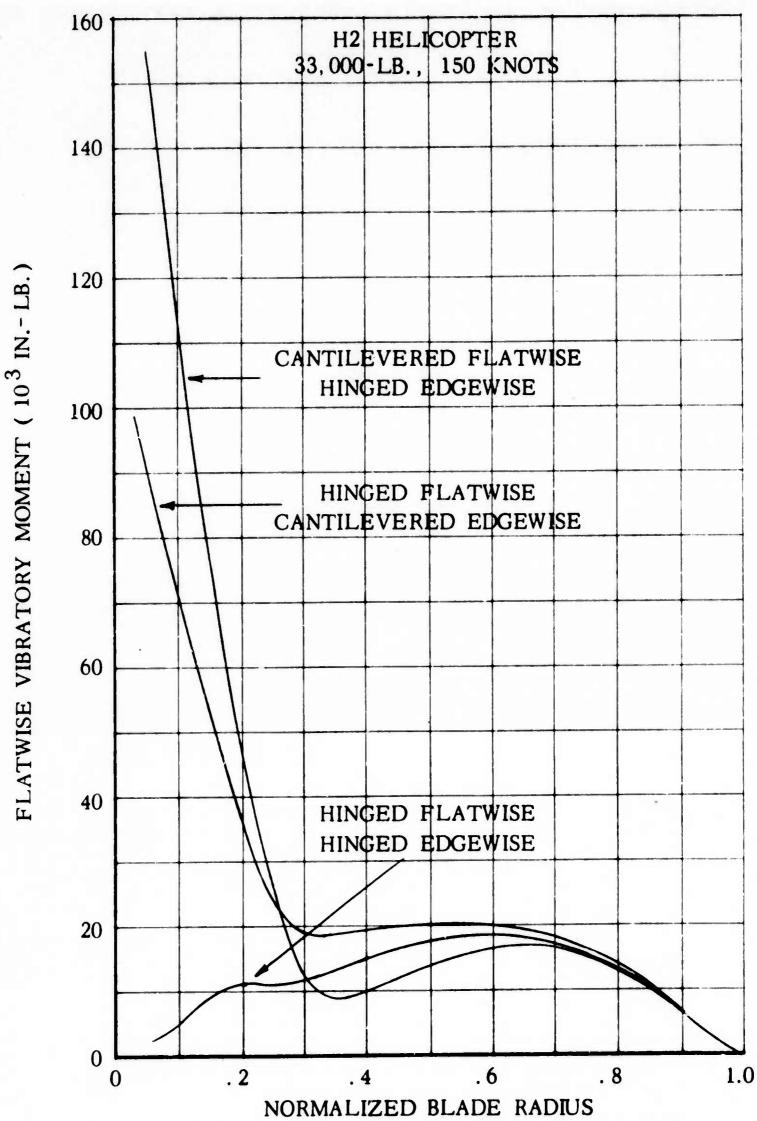
EDGEWISE ROOT SHEAR, LB.

FIG. 11.7 EFFECT OF ROTOR HUB MOTION ON BLADE ROOT EDGEWISE SHEAR



EDGEWISE ROOT SHEAR, LB.

FIG. 11.8 EFFECT OF ROTOR HUB MOTION ON BLADE ROOT EDGEWISE SHEAR



NORMALIZED BLADE RADIUS
FIG. 11.9 CHANGE IN FLATWISE MOMENT
WITH CHANGE IN ROOT RESTRAINT

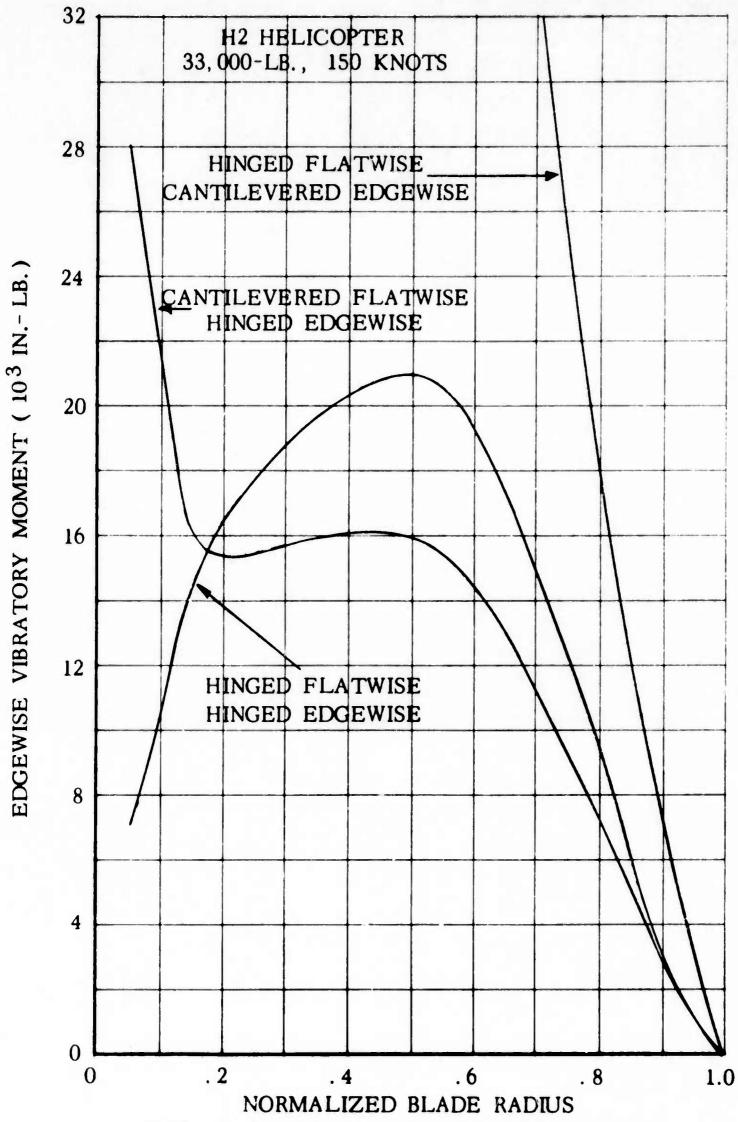


FIG. 11.9A CHANGE IN EDGEWISE MOMENT
WITH CHANGE IN ROOT RESTRAINT

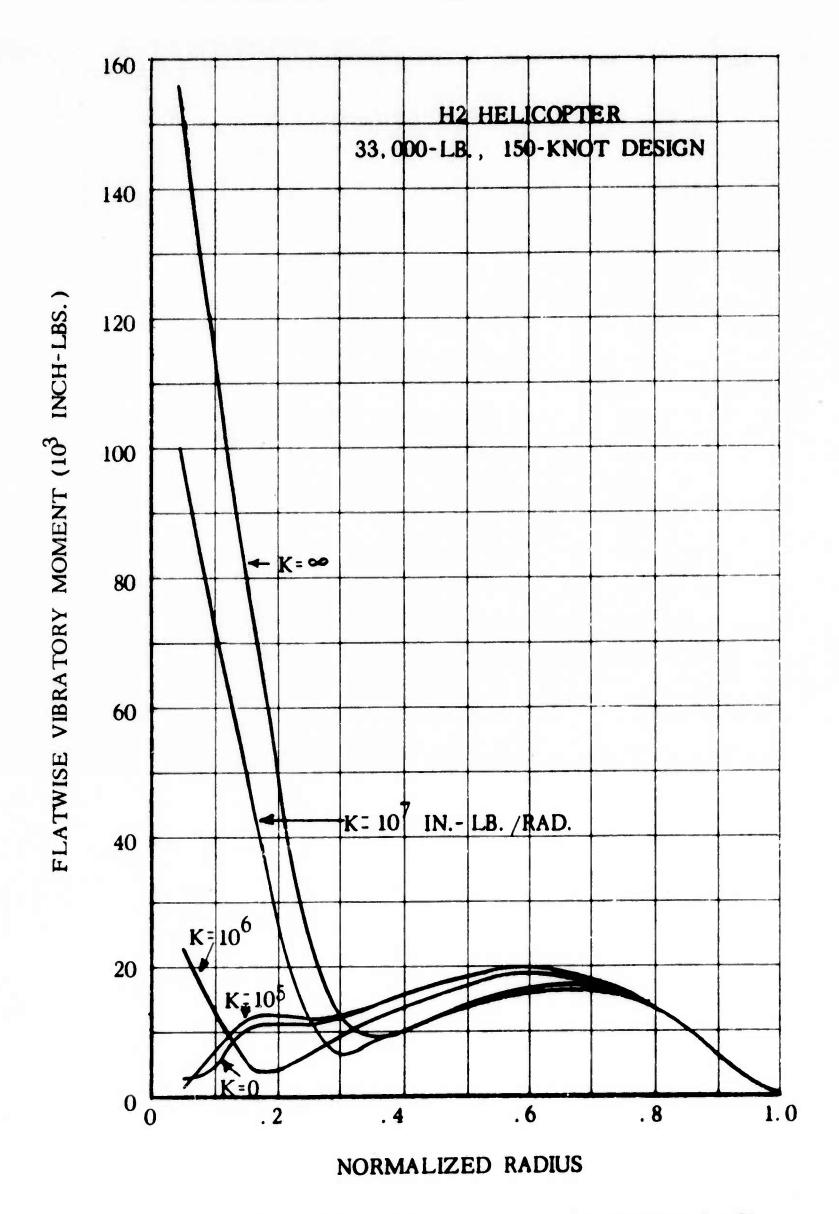


FIG. 11.10 EFFECT OF FLATWISE ROOT FLEXIBILITY ON FLATWISE MOMENT

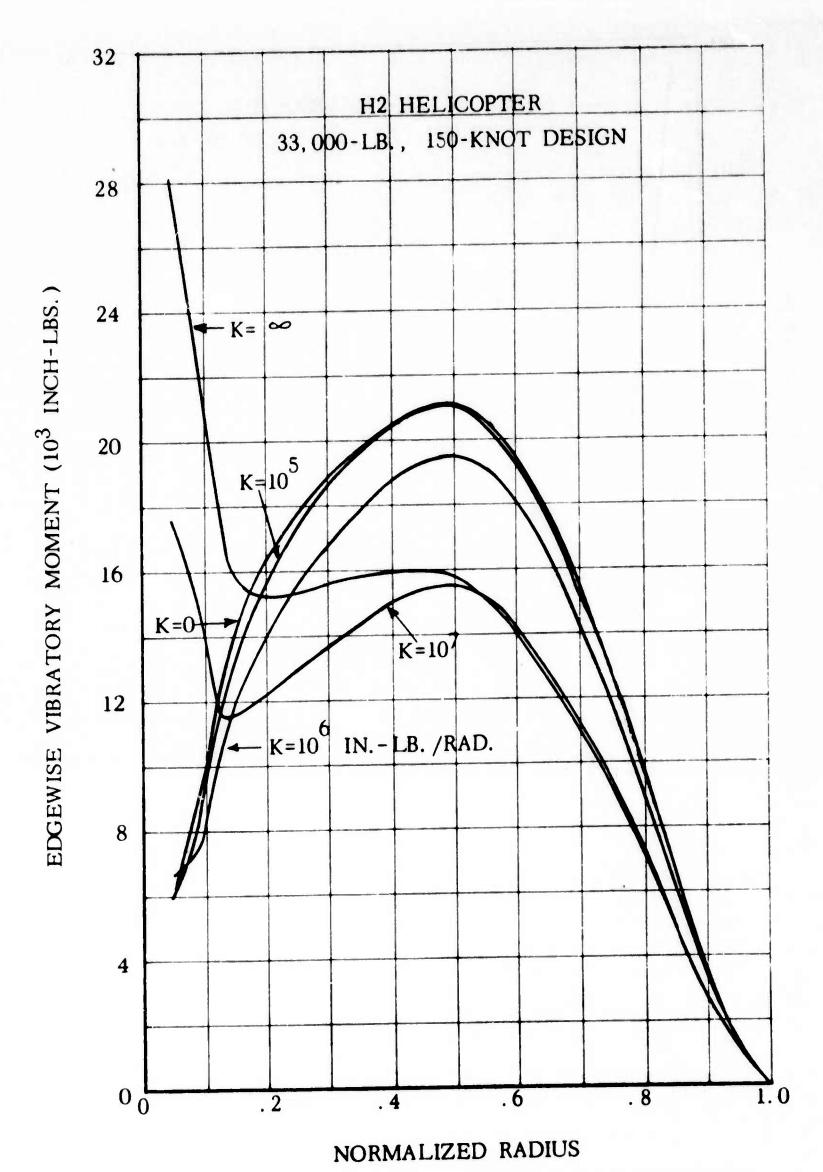
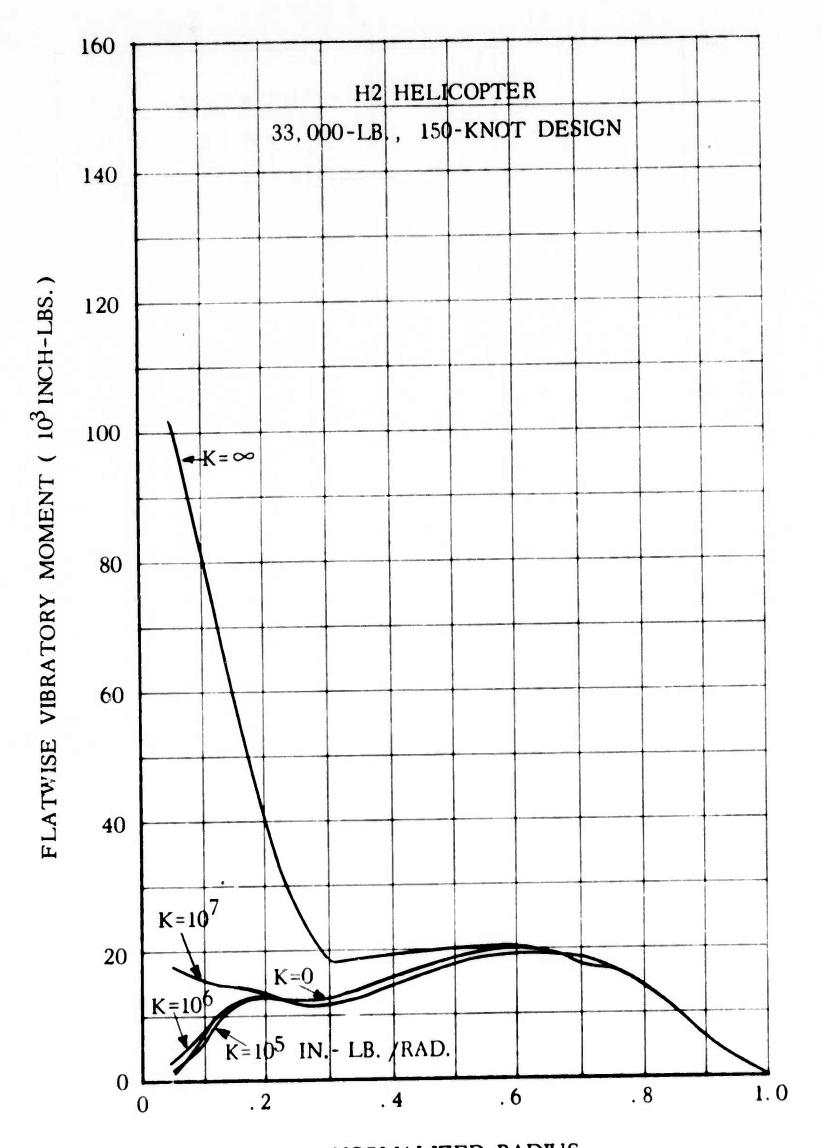


FIG. 11. 11 EFFECT OF FLATWISE ROOT FLEXIBILITY ON EDGEWISE MOMENT



NORMALIZED RADIUS
FIG. 11.12 EFFECT OF EDGEWISE ROOT FLEXIBILITY
ON FLATWISE MOMENT
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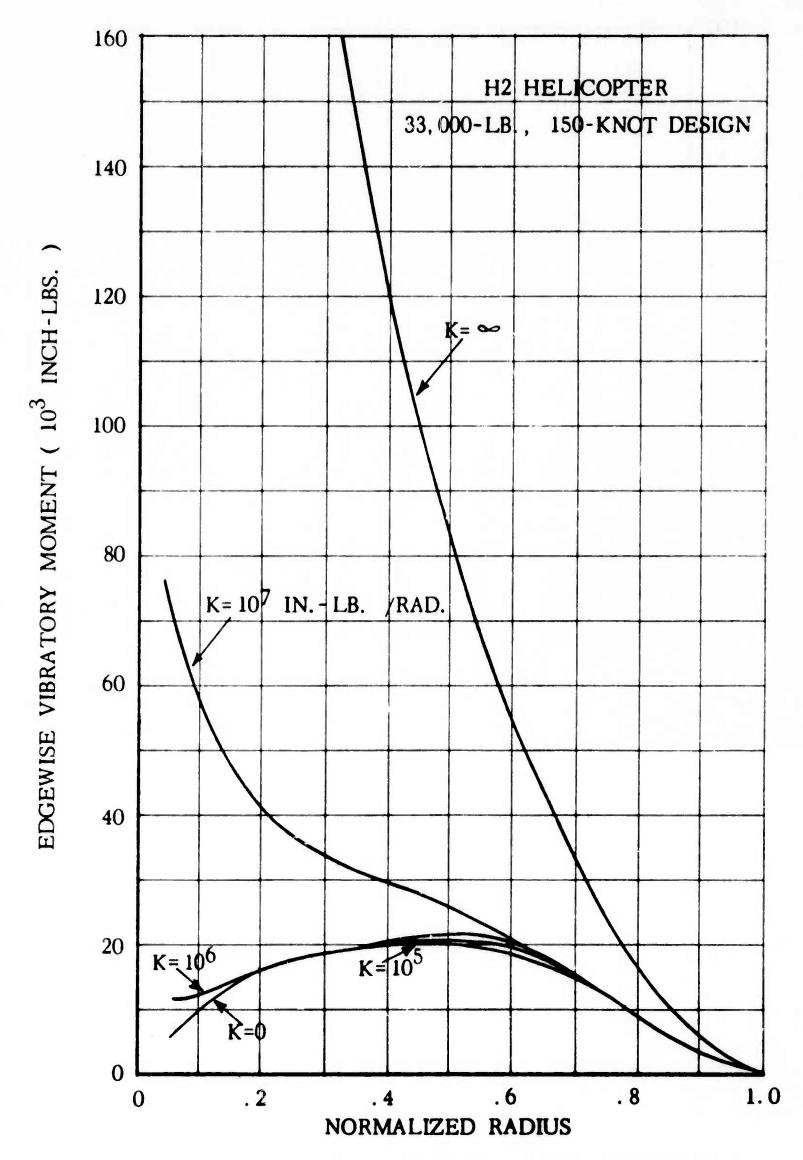
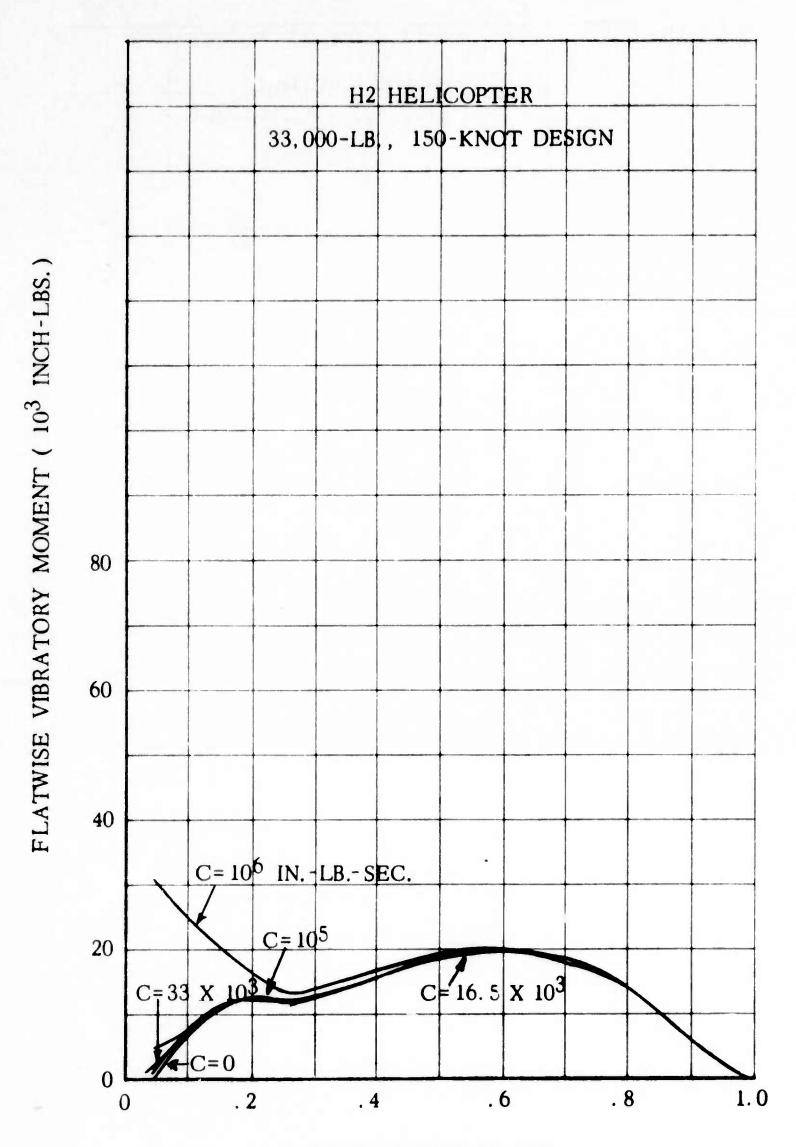
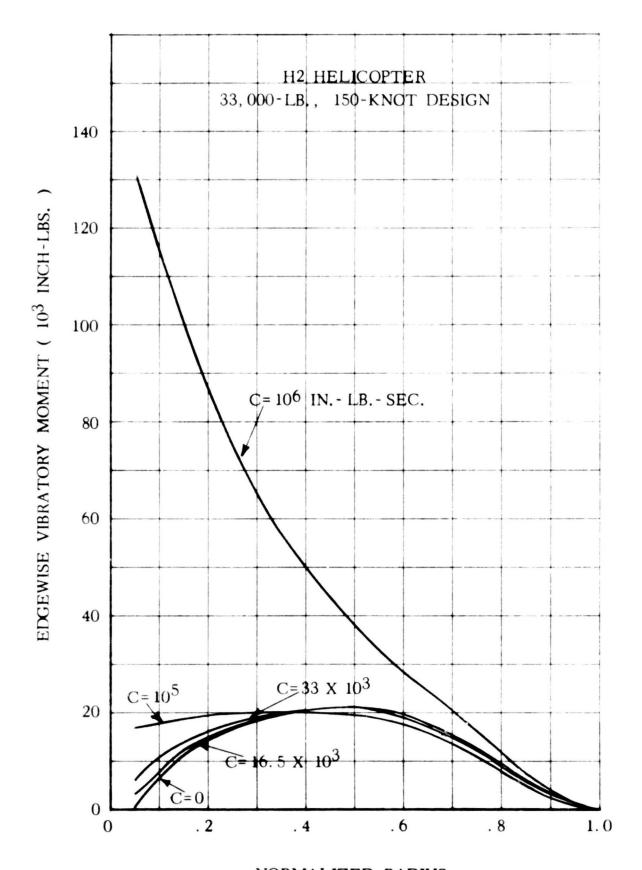


FIG. 11.13 EFFECT OF EDGEWISE ROOT FLEXIBILITY
ON EDGEWISE MOMENT

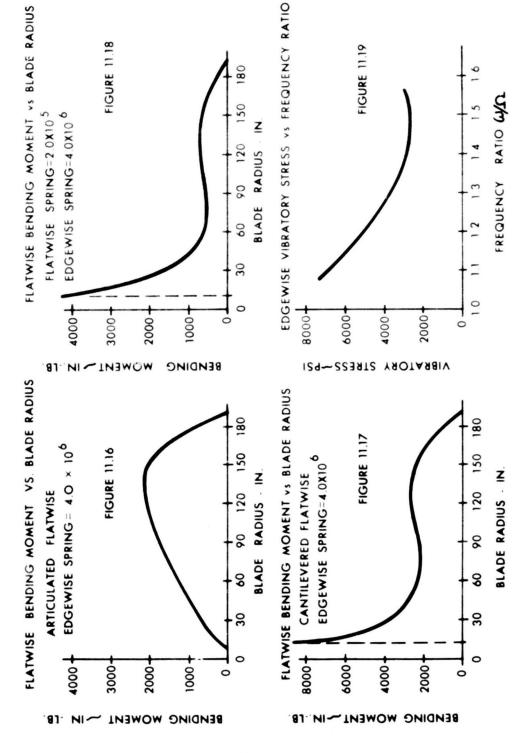


NORMALIZED RADIUS
FIG. 11.14 EFFECT OF EDGEWISE DAMPER
ON FLATWISE MOMENT



NORMALIZED RADIUS
FIG. 11.15 EFFECT OF EDGEWISE DAMPER
ON EDGEWISE MOMENT

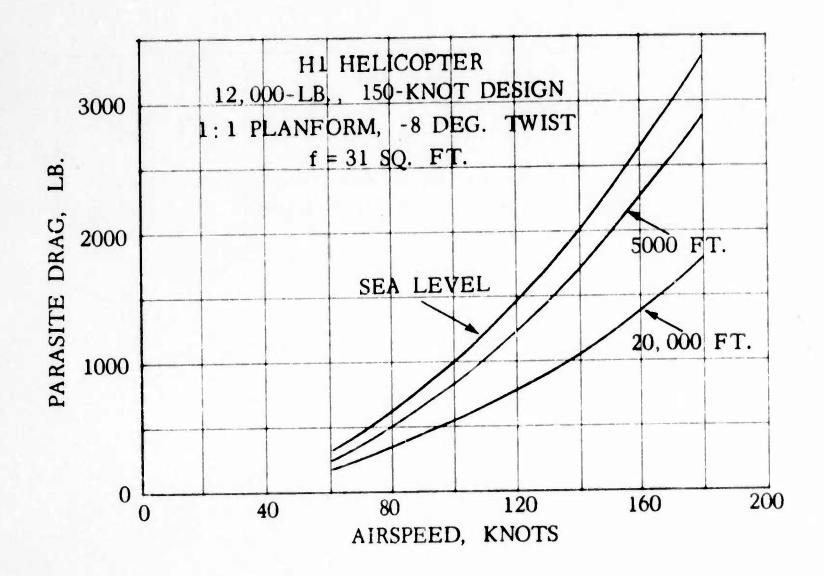
EFFECT OF ROOT FLEXIBILITY ON BENDING MOMENTS AND STRESSES CALCULATED FOR LOCKHEED CL-475 HELICOPTER

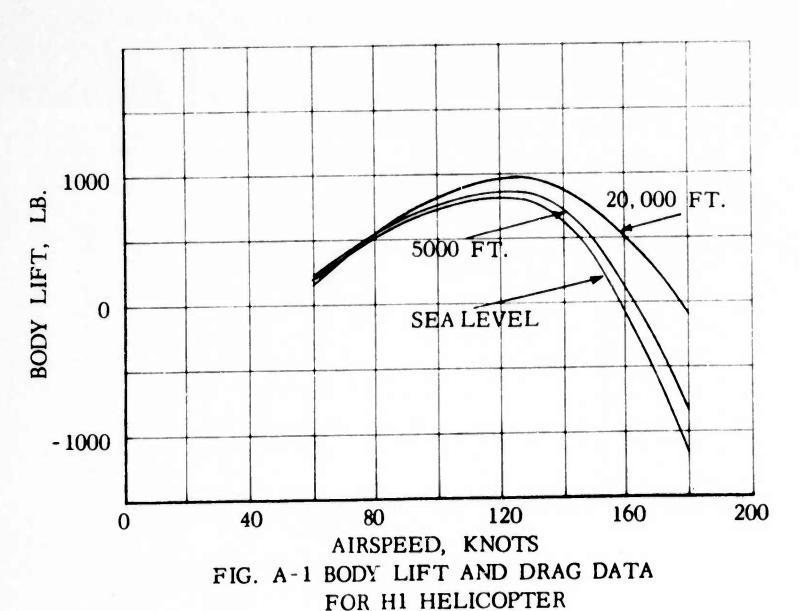


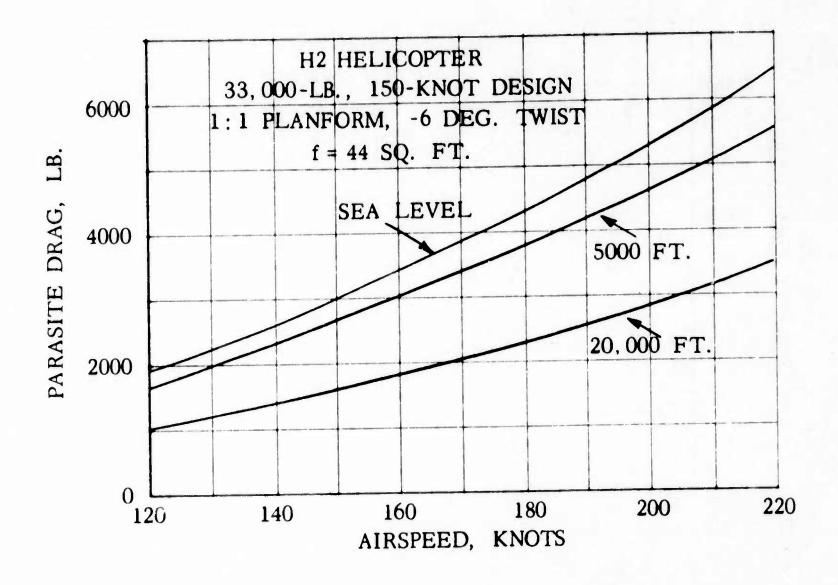
# APPENDIX A FUSELAGE LIFT AND DRAG DATA

### **ILLUSTRATIONS**

Figure	Aircraft	Page
A - 1	H1 Helicopter	190
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A-8	C4 Compound	196







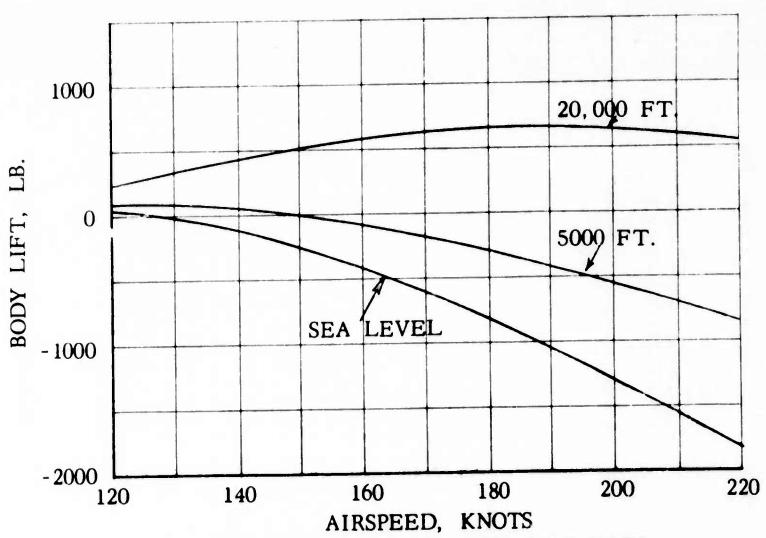
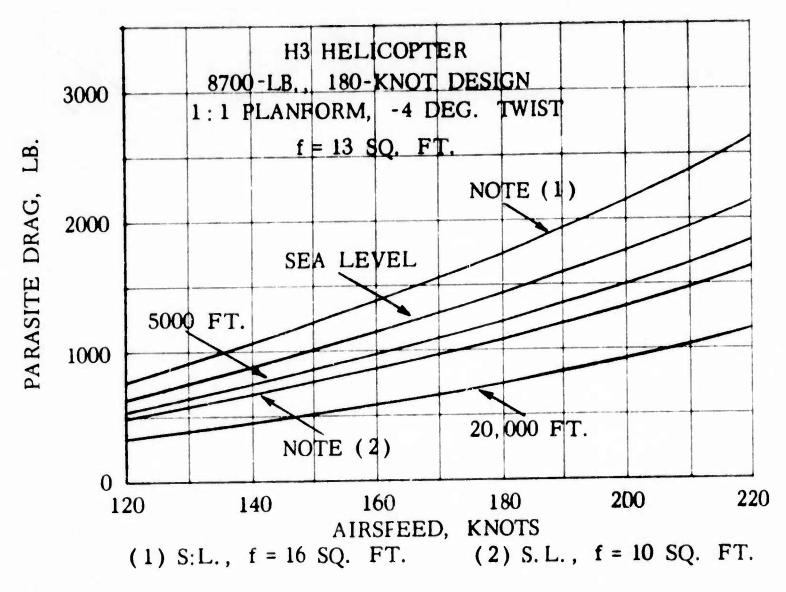


FIG. A-2 BODY LIFT AND DRAG DATA FOR H2 HELICOPTER



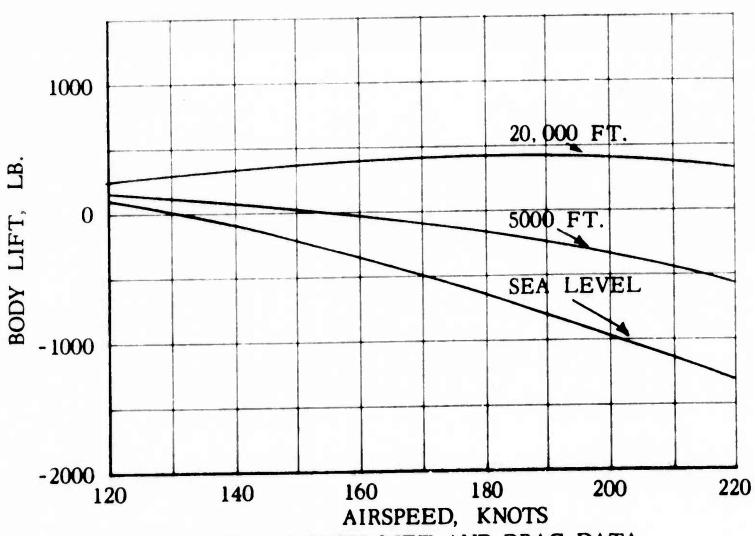
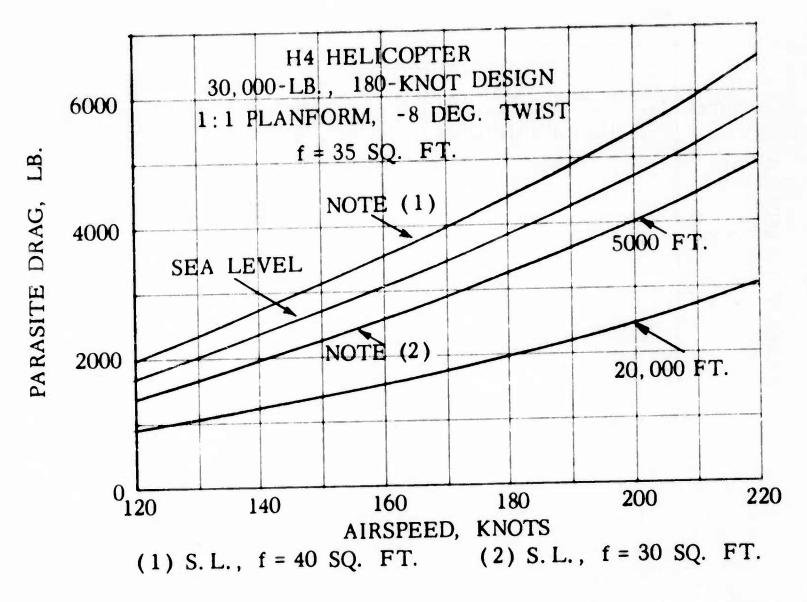
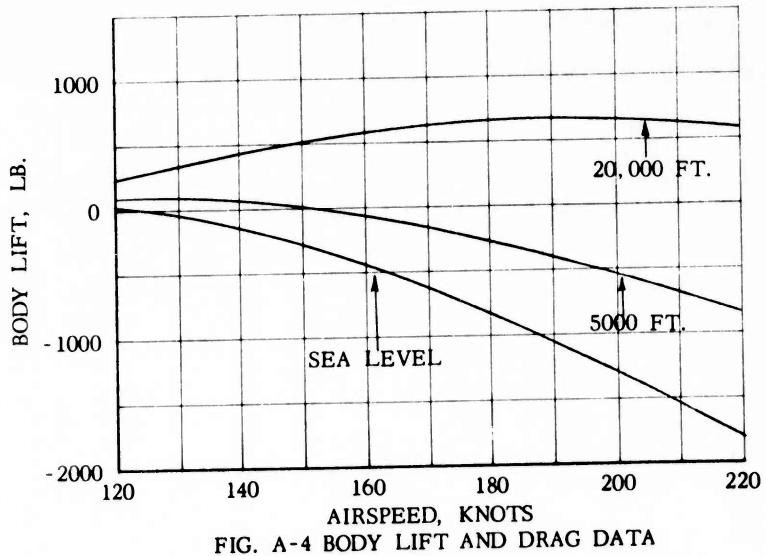


FIG. A-3 BODY LIFT AND DRAG DATA FOR H3 HELICOPTER





193

FOR H4 HELICOPTER

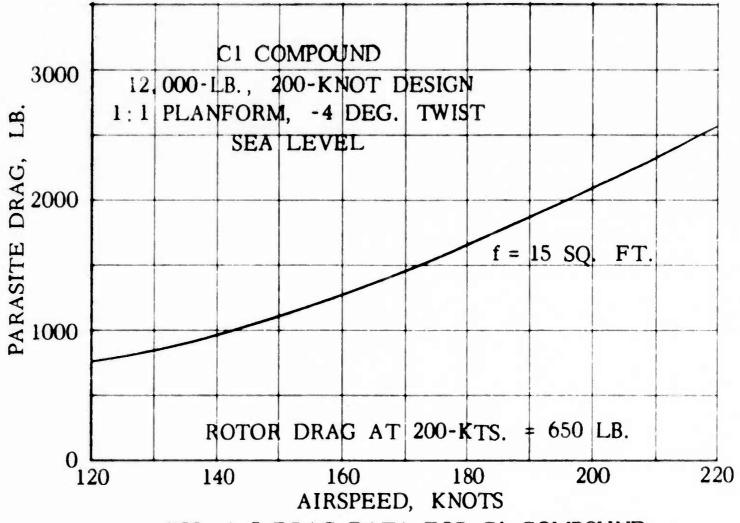


FIG. A-5 DRAG DATA FOR C1 COMPOUND

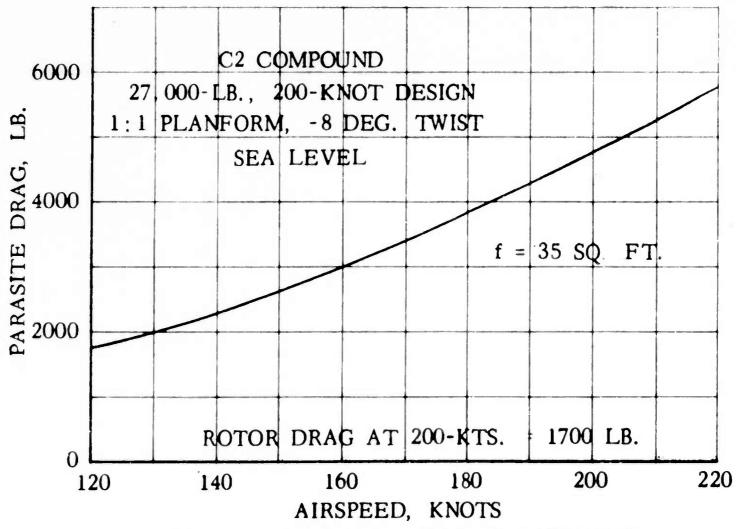


FIG. A-6 DRAG DATA FOR C2 COMPOUND

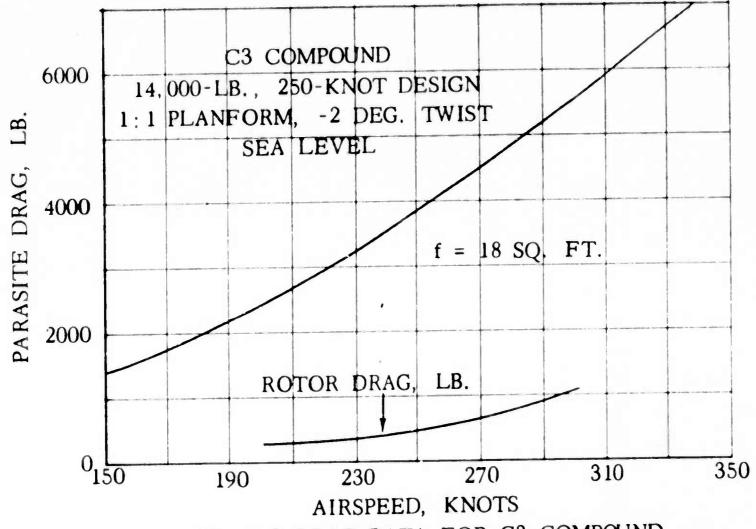


FIG. A-7 DRAG DATA FOR C3 COMPOUND

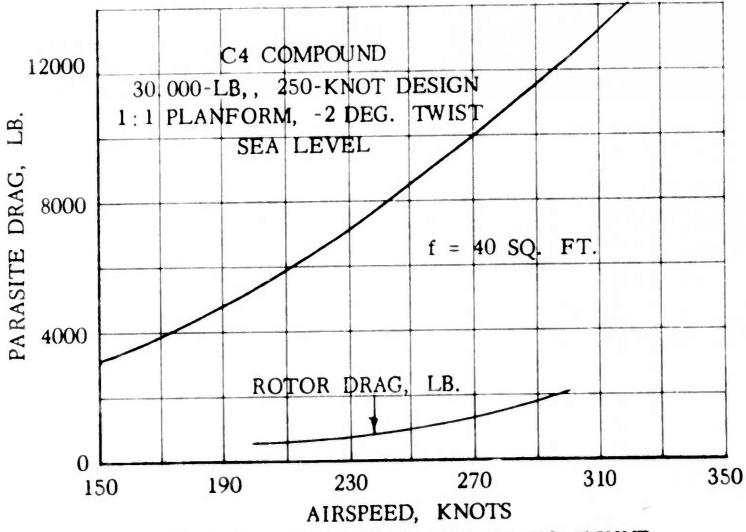


FIG. A-8 DRAG DATA FOR C4 COMPOUND

# APPENDIX B

# BLADE DATA

# **TABLES**

Aircraft	Planform	Table	Page
H1	1:1	B-1	199
	N. L.	B-2	200
	3:1	B-3	201
	1:2	B-4	202
H2	1:1	B-5	203
	N. L.	B-6	204
	3:1	B-7	205
	1:2	B-8	206
НЗ	1:1	B-9	207
	N. L.	B-10	208
	3:1	B-11	209
	1:2	B-12	210
H4	1:1	B-13	211
	N. L.	B-14	212
	3:1	B-15	213
	1:2	B-16	214
H1-R	1:1	B-17	215
	N. L.	B-18	216
	3:1	B-19	217
	1:2	B-20	218
H2-R	1:1	B-21	219
	N. L.	B-22	220
	3:1	B-23	221
	1:2	B-24	222
H3-R	1:1	B-25	223
	N. L.	B-26	224
	3:1	B-27	225
	1:2	B-28	226
H4-R	1:1	B-29	227
	N. L.	B-30	228
	3:1	B-31	229
	1:2	B-32	230

Aircraft	Planform	Table	Page
Cl	1:1	B-33	231
	<b>N</b> . L.	B-34	232
	3:1	B-35	233
	1:2	B-36	234
C2	1:1	B-37	235
	N. L.	B-38	236
	3:1	B-39	237
	1:2	B-40	238
C3	1:1	B-41	239
	N. L.	B-42	240
	3:1	B-43	241
	1:2	B-44	242
C4	1:1	B-45	243
	N. L.	B-46	244
	3:1	B-47	245
	1:2	B-48	246
C1-R	1:1	B-49	247
	N. L.	B-50	248
	3:1	B-51	249
	1:2	B-52	250
C2-R	1:1	B-53	251
	N. L.	B-54	252
	3:1	B-55	253
	1:2	B-56	254
C3-R	1:1	B-57	255
	N. L.	B-58	256
	3:1	B-59	257
	1:2	B-60	258
C4-R	1:1	B-61	259
	N. L.	B-62	260
	3:1	B-63	261
	1:2	B-64	262

TABLE

IN.4 6.80 5.70 6.60 .60 8.20 8.50 9.00 9.90 4.00 5.50 6.00 6.30 .30 .90 SIGN .80 30.00 00.00 00.00 TOR 2YY 3, 5.50 5.50 5.80 5.00 6.20 6.40 0.00 5.00 5.10 6.13 6.58 6.70 7.95 TION 6.92 2.50 5.03 150-KNOT DESIGN IYY 4 24.30 24.80 27.00 27.30 28.00 35.00 20.60 20.90 28.50 29.30 29.80 30.50 23.70 24.00 0.10 E06E-20.30 20.50 HISE 1-1 PLANFORM, ARTICULATED BLADE GROSS WEIGHT 12,000 LB., 150-KNOT D 11N.3 1.80 1.90 1.95 2.95 2.95 2.95 2.95 3.60 3.60 SEC-1.82 1.84 1.90 4.00 . 90 XXZ BLADE DATA HI HELICOPTER FLAT-HISE 4.NI) .80 1.95 2.99 2.99 2.51 2.51 2.51 2.51 4.40 16. 1.93 3.04 2.91 45.00 75.00 XXI BASIC WALL THICK-(IN.) 0.151 0.151 0.158 0.158 0.163 0.169 0.175 0.180 NESS 0.191 000. -210 .265 0000 0.145 -202 .000 0.072 SEGMENT 2.56 12.57 9.19 9.18 9.29 9.14 9.45 9.37 9.91 9.73 8.78 9.06 8.53 10.51 84-17 WEIGHT (18.) 18.25 CHORD ( IN. ) 372.00 334.80 334.80 297.60 279.00 241.80 223.20 204.60 186.00 186.00 186.00 187.40 130.20 111.60 55.80 37.20 18.60 12.63

12.98 13.00 13.10 13.20 13.25 13.35 13.40

12.94

AREA IN 2

LINE

-8 DEG. DESIGN THIST

DEG

-4, -8, -16

0

THIST VARIATIONS

50.00

13.68 14.10 00.00

13.47 13.52 13.58

RADII (IN.)

TABLE 8-2

BASIC BLADE DATA HI HELICOPIER N.L. PLANFORM, ARTICULATED BLADE GROSS WEIGHT 12,000 LB., 150-KNOT DESIGN

			WALL	FLAT-	SEC-	EDGE-	SEC- TION	TOR- S I ON	MID-
AD I I	CHORD	WEIGHT	ESS	×	×	IYY	77	7	ARE
	(IN.)	ILB.	=	( t.N1)	-	Z	(IN. ()	•	( N N N N N N N N N N N N N N N N N N N
22	0	5	16	0.12	•	8	8	4.	.2
7		R	32			. 1	-	6	.5
	1	5	22	0.68		7.	8	.2	9.
	6		17			3.7	8	6.	9.68
	7		14	2.00		3.8	7	0	6.
29	8.2	7	.15	. 4		6.0	7.		ë
04	8.2	0	15			3.7	Si	9.	-
	2		15	-		4.0	9.	8	13.13
23.20	18.25	9.45	0.163	2.29	2.10	24.30	5.50	1.00	13.20
7	8.2		116	W		4.8	8	.3	3.2
4	8	5	111	1	- 60	7.0	7	•	3
7	8	5	118	S	•	7.3	.2	6.	3.3
	8	0	118	9	•	8.0	-2	.2	3.4
9	8.2	9.1	119	1	•	8.5	4.	8.50	13.47
-	8	-	51.		•	9.3	W)	0	3.5
0		0	.20	2.91		8.6	-	5	S
	8		2		2.70	0.5	5	4.0	9.
v		5	.2	4.40	_	5.0	5	0.0	-
1			0	45.00		0.0	4	0.0	0.0
			0	0		5.0	15.00	•	Ŏ
00.01			6	0 5	18.00	5.0		00.0	0
12.03	01.0	5	5	•					

THIST VARIATIONS O, -4, -8, -16 DEG.

TABLE 8-3

BASIC BLADE DATA
HI HELICOPTER
3-1 PLANFORM, ARTICULATED BLADE
GROSS WEIGHT 12,000 LB., 150-KNOT DESIGN

	GME	WALL THICK-	FLAT- WISE	SEC-	EDGE-	SEC- TION	TOR- S10N	MID-
WEIGHT	NESS		IXX	7 X X 7	1	7.4.7		AREA
LB.)	Z		(IN.4)	(IN.)	(IN. 4)	(1N.C)	_	O'NI)
2.56	0.100		0.45	0.56	5.17	1.64		3.67
12.57	0.200		16.0	1.12		3.29		7.34
9.51	0.180		1.16	1.31		3.71		9.04
00.00 9.19 0.170	0.170		1.45	1.51		4.11	4.38	10.89
9.18 0.160			1.74	1.68		4.53		12.81
9.29 0.150			2.11	1.89		4.93		15.05
9.03 0.140			2.45	2.10		5.82		16.83
9.14 0.140			2.94	2.37		6.59		19.11
00 9.45 0.130			3.54	2.68		6.81		21.17
9.37 0.130			4.10	2.95		7.42		24.34
40 9.91 0.130			4.82	3.29		8.44		27.02
9.94 0.130			5.54	3.60		9.05		30.16
80 10.01 0.120			6.27	3.91		82.6		32.67
9.73 0.120			7.43	4.42		10.70		36.03
20 8.78 0.120			8.58	4.89		11.81		39.28
9.06 0.120			9.6	5.43		12.68		45.95
8.53 0.120		-	1.59	6.07		13.79		46.79
10.51 0.140		-	7.75	8.99		15.88		49.92
55.21 1.000		4	2.00	•		10.00		50.00
84.17 2.000		1	5.00	18.00		15.00		100.00
20.46 2.000			15.00	18.00	75.00	15.00	100.00	100.00

THIST VARIATIONS 0, -4, -8, -16 DEG.

TABLE 8-4

BASIC BLADE DATA
HI HELICOPTER
1-2 PLANFORM, ARTICULATED BLADE
GROSS WEIGHT 12,000 LB., 150-KNOT DESIGN

			AL		ш	DC	SEC-		MID
		EGME	I	S	10	ISI	10	SION	_
AD	HOR	9	NESS	IXX	ZXX ~	LAAT	>	7	AREA
( .N.)	(IN.)	(18.	Z		-	Z	O.NI	(IN.	ž
72.0	0	S	90		1.02	2.9	-	.5	3
53.4	4.0	5	.12		0	5.8	4	-	8.7
34.8	9.6	9.5	.13	.3	1.98	4.4	7	8	7.5
316.20	19.30	61.6	0.138	.2	1.96	23.24	5.12	6.68	16.56
97.6	8.8	7.	.14	2.14	1.90	2.1	0	4.	5.6
19.0	8.4	.2	.15	2.08	1.88	1.2	0	6.21	4.8
4.09	7.8	0	.15	1.98	1.85	2.4	(4	-	13.74
41.8	7.3	7.	91.	1.92	8	1.3	-	0	
23.2	6.7	4.	.18	1.84	1.84	9.6	0	9.	11.79
9.40	6.2	6	.19	1.75	1.80	9.0	8	4.	.9
86.0	5.7	6.	.20	1.67	1.77	9.2	0	.2	0
67.4	5.2	6.	.22	1.57	1.72	8.0	8	0.	.2
48.8	4.6	0	.23	1.45	1.65	5.7	-	1	
30.2	4.1	9.1	.25	1.36	1.60	5.6	Si	S	9.
11.6	9.	1.	.27	1.25	1.53	4.6	N	4.23	0
93.0	0	0	.30	1.11	1.42	3.2	.2	6.	0
4.4	S	2	.32	1.00	1.33	-	0	3.63	5.35
5.8	.5	0.5	***	1.06	1.47	9.	7	8	.2
7.2	0	5.2	90.	5.0	14.00	0.	0.0	0.0	0.0
8.6	0	4.1	00.	75.00	0	0	0	0.	
2.6	0.	4.	00.	5.0	8.0	0	5.0	00.0	0000

THIST VARIATIONS 0. -4. -8. -16 DEG.

TABLE 8-5

BASIC BLADE DATA
H2 HELICOPTER
1-1 PLANFORM, ARTICULATED BLADE
GROSS WEIGHT 33,000 LB.: 150-KNOT DESIGN

THICK- WISE NESS IXX (IN.) (IN. 0.081 1.87 0.162 3.75 0.183 4.20 0.204 4.75 0.212 5.05 0.214 5.42	110N 2XX 2XX 11.38 2.92 3.24 3.62 3.62 4.15	NISE 1YY (IN.4) (10.90 39.80 42.90 53.00 55.30 64.80		5.90 12.70 15.00 16.90 16.55 18.00	LINE AREA (IN. <sup>2</sup> ) 9.55 19.20 19.40 19.73 19.86 20.15
UESS [XX [IN.] (IN. 1081 1.8 162 3.7 183 4.2 204 4.7 212 5.0 212 5.0 221 5.5	XZ MONOBIN	××××××××××××××××××××××××××××××××××××××	N 8 9 9 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	86 5 9 1 2 L	AREA IN 8 19.2 19.4 19.8 20.1
1081 162 162 183 204 204 212 212 216 5.6 5.6 5.6 5.6 5.7 5.8	Z WONOBING		8 8 8 8 6 10 10 10 10 10 10 10 10 10 10 10 10 10	8 4 5 6 7 6 8 6 8 6 9 6 9 6 9 6 9 6 9 6 9 6 9 6 9	9.5 19.2 19.4 19.8 20.1
162 162 183 204 204 212 212 216 5.0 221 5.5 5.5 5.5 5.5 5.5 5.5 5.5 5.5 5.5 5.	W & W & & & W & W & W & & W & & W & & W & & W & & W & & W & & W & & W & & W & & W &		98.88	96669	0000000
162 183 204 204 212 212 5.0 221 5.5 5.5 5.5 5.5 5.5 5.5 5.5 5.5 5.5 5.	040844	8 0 0 M 8 M	97.8	7044 0000	24.60
204 4.7 202 4.7 212 5.0 216 5.4 221 5.5 224 5.6	79847	90696	8826	0.4.0	47.800
204 4.7 212 5.0 216 5.4 221 5.5 224 5.6	22.4	0 6 6 6	9.8	6.5	9.6
212 216 216 5.4 221 5.5 5.5 5.6	8 - 7 -	5.8	0.5	6.5	9.8
.216 5.4 .221 5.5 .224 5.6	120	5.3	1.3	8.0	0.1
.221 5.5 .224 5.6	.2	5.3	•		0.1
.224 5.6	96 7	)	1.4	9.0	
228 5.8	07.4	6.0	1.6	9.3	0.2
	W	6.8	1.7	9.1	0.2
.232 5.9	4.	1.3	1.9	0.0	0.2
.237 6.0	4.	8.0	2.0	0.3	0.3
.241 6.1	4.55	8.8	2.1	0.1	0.3
.245 6.2	4.60	9.3	2.3	1.0	4.0
.249 6.4	4.70	0.1	2.4	1.4	4.0
.258 6.4	5.	2.0	2.8	1.8	0.5
.290 8.1	8	0.8	4.3	3.4	1.0
375 24.1	3.2	4.0	2.2	8.8	4.6
000 1000	5.0	00.0	5.0	0.0	00.0
1000	5.0	00.0	5.0	50.0	0.0
	5	0	5.0	50.0	0.0
•001	•				
.375 24.1 .000 100.0 .000 100.0	0000		4000	24.00 22.2 00.00 25.0 00.00 25.0 00.00 25.0	24.00 22.20 48.8 00.00 25.00 100.0 00.00 25.00 150.0

DESIGN THIST -6 DEG.

THIST VARIATIONS 0. -4. -8. -16 DEG.

BASIC BLADE DATA
H2 HELICOPTER
N.L. PLANFORM, ARTICULATED BLADE
GROSS WEIGHT 33,000 LB., 150-KNOT DESIGN

			AL	_	W	90	W.	TOR-	] ]
		EGME	THICK-	WISE	TION	WISE	TION	SION	LINE
ADI	HOR	WEIGHT	ESS	×	××		ZYY	7	R
(IN.)	(IN.)	(18.	Z	(IN.4)	-	(IN.4)	(IN.3)	(IN.4)	Z
32.0		6.	. 18	.2	.3	8	5		
10.4	1.8	9.6	.36	5	1.	9.	7.	.2	.2
88.8	5.7	4.5	.28	.5	9.	7.1	3		6.
67.2	9.7	5.7	.24	0	.5	5.5	.2	9.0	6.4
45.6	3.6	5.7	.21	0.	.8	5.3	0.2	6.5	9.8
24.0	3.6	7.1	.21	4.	7.	4.8	.3	8.0	0.1
302.40	23.65	10.29	0.221	5.58	4.20	65.30	11.45	19.05	20.15
80.8	3.6	7.6	.22	9.	.2	6.0	9.	9.3	0.2
59.2	3.6	7.0	.22	8	.3	6.8	1.	1.6	0.2
37.6	3.6	8.0	.23	6.	*	7.3	6.	0.0	0.2
16.0	3.6	7.7	.23	0.	4.	8.0	0.	0.3	0.3
4.46	3.6	9.9	.24	7.	.5	8.8		1.0	0.3
72.8	3.6	4.9	.24	.2	.6	9.3	6.	1.0	4.0
51.2	3.6	4.9	.24	4.	1.	0.1	2.4	1.4	4.0
29.6	3.6	7.3	.25	4.	6.	2.0	2.8	1.8	0.5
08.0	1.	8.4	.29	7.	.8	0.8	4.3	3.4	1.0
86.4	1.	8.1	.37	4.1	3.2	4.0	2.2	8.8	4.6
4.8	-	4.6	00.	0000	5.0	0.0	5.0	0.0	0.0
3.2	1.	7.1	00.	0	25.00	0.0	0	0.0	00.00
4.0	1.	4.5	00.	00.00	5.0	0000	5.0	0.0	0.0

THIST VARIATIONS O. -4, -8, -16 DEG.

TABLE 8-7

BASIC BLADE DATA

56.39 46.60 94.99 26.07 31.00 100.00 22.37 72.42 100.00 37.43 41.84 49.93 19.10 29.59 16.35 AREA LINE - ZI ( IN. 56.03 19.09 25.83 34.13 294.40 48.29 00.001 11.63 77.42 39.16 44.39 62.41 SION 22.44 14.43 N1) 25.00 18.35 15.35 22.23 12.45 28.26 6.77 54.83 TION 5.64 8.66 9.92 14.70 20.58 23.82 .82 3-1 PLANFORM, ARTICULATED BLADE S WEIGHT 33,000 LB., 150-KNCT DESIGN (IN.4) 486.30 47.11 65.10 10.11 20.22 26.48 38.58 155.30 177.70 200.20 246.50 76.43 95.99 113.00 127.60 143.90 86.88 EDGE-WISE IYY LXX (IN. 3) 25.00 7.93 8.44 1.72 2.18 2.73 3.21 3.83 4.35 4.76 5.03 6.84 7.20 6.28 11.36 46.59 25.00 TION 0.86 SEC-HZ HELICOPTER IXX (IN.4) FLAT-26.92 17.31 5.45 6.62 7.66 8.30 11.90 13.65 117.70 00.00 00.00 00.00 1.79 2.48 3.35 10.40 19.25 WISE 4-24 14.84 0.89 THICK-GROSS WEIGHT 3.000 3.000 (IN.) 0.113 0.226 0.232 0.239 0.229 0.216 0.196 0.180 0.180 1.157 .155 1.167 0.193 NESS 0.164 MALL SEGMENT 10.29 17.02 18.04 38.11 59 15.77 15.74 17.14 17.71 19.9 16.42 9.60 16.42 4.51 6.97 **HEIGHT** (18.) 15.80 17.40 18.90 20.50 22.00 23.70 26.80 26.80 28.50 30.00 31.60 34.70 36.40 16.90 16.90 16.90 ORD -35 194.40 172.80 151.20 129.60 108.00 64.80 43.20 24.00 367.20 345.60 324.00 302.40 237.60 216.00 280.80 432.00 388.80 RADII (IN.)

TWIST VARIATIONS 0, -4, -8, -16 DEG.

TABLE 8-8

BASIC BLADE DATA
H2 HELICOPTER
1-2 PLANFORM, ARTICULATED BLADE
GROSS WEIGHT 33,000 LB., 150-KNOT DESIGN

			AL	FLAT-	EC	90	EC	TOR-	10
		EGME	THICK-	WISE	TION	WISE	TION	10	LINE
RADII	CHORD		ES		××	IYY	277	7	ARE
-	(IN.)	(18.	Z		-	Z	Z	~ Z	Z
23	0	0	.07	4	5	5.1	S	4	9-1
4	4	9.6	14	00	0	3.2	-	6.+	.3
88.88	5.7	5	16	0	2	1.2	9	5.4	7.5
57.2	2	5.7	19	4	9	9.8	6.0	3.2	5.5
65.6	4	5.7	.20	4	1	3.2	1.2	3.2	1
24.0	3.6	7.1	.21	.3	8	4.5	2.3	8.9	7 - 1
02.4	2.9	0.2	.22	7	1	7.0	2.0	1.7	9.6
8,08	6 6	7.6	.23	6	9.	7.8	1.7	2.0	9.3
50.0	9 - 1	7.0	-25	9	5	4.4	1.4	5.1	6 - 1
37.6		0 8	26	4	3	1.3	1.1	5.2	5.7
16.0		7.7	.28	0	m.	7.9	0.8	4.4	5.4
4	1 4	9 9	29	7	7	4.6	4.	3.4	4.1
72.8	8.9	9-9	31	4	0	1.1	0.0	2.4	2 - 8
51.2	8.2	4-9	.33	7	8	7.8	5	1.5	9 - 1
29.66	7.5	7.3	.36	8	•	5.1	1.	0.5	4.0
	7.0	8.4	.43	6	5	5.0	r.	0.5	0-3
7 9		8.1	.71	2	9.	8.0	• 6	3.9	4.1
4.8	-	4.6	00.	00.0	5.0	00.0	5.0	00.0	00.0
7	-	7.1	3.000	100.00	25.00	100.00	25.00	150.00	100.00
24.00	6.70	84.59	.00	00.0	5.0	00.0	5.0	50.0	00

THIST VARIATIONS 0, -4, -8, -16 DEG.

TABLE 8-9

BASIC BLADE DATA
H3 HELICOPTER
1-1 PLANFORM, ARTICULATED BLADE
GROSS WEIGHT 8,700 LB., 180-KNOT DESIGN

			AL		Ċ	9	U	TOR-	01
		SEGMENT	THICK-	E I SE	110N	WISE	NOI L	2015	LINE
RADII	CHORD	FIGH	٦ :	K .	<	- 2	7 7	ANI	IN
N.	Z	<b>LB.</b>	Z	-	Ž.	Z	Ė		•
9	~	0	0	0	6	.3	5	6	5.9
		10	7	0	8	5.0	0	6	5.9
7 60	,,	8	14	0	8	7.1	7	0	5.9
7 7 9	10	4	15	0	0	9.6	-	-	3.0
8	100	. 4	15	0	6	0.1	.2	3	3.0
52.0	8.2	7	15	-	0	3.8	S	9	3.1
2, 2	2	4	16	7	0	4.0	9	6	3.1
	7	4	16	3	7	4.5	1	7	3.2
			17	3	.2	4.8	8	4	3.2
34.9	- C	0	17	4	~	7.0	7	9	3.3
		0	8	S	(1)	7.2	.2	6.	3.3
7100			1 8	N	(1)	7.8	.2	.2	3.4
136 60	18.25	9-16	0-190	2.68	2.40	28.50	04.9	8.50	13.45
			119	-		9.0	2	1	3.5
00			.20	8		9.5	-	0	r.
40			.20	6	•	0.0	8	•	3.6
	4	4	2	-	•	1.2	-	4.0	3.1
		2	.27	83	•	7.8	•	0.0	<b>a</b>
7		0	.5	0.0	•	0.0	0.0	5.0	0.0
			0	5.0	•	5.6	15.00	00.0	0.0
0 0			C		•	5.6	5.6	0.0	100.00
7	•				, ,				

DESIGN THIST -4 DEG.

TWIST VARIATIONS 0. -4, -8, -16 DEG.

BASIC BLADE DATA
H3 HELICOPTER
N.L. PLANFORM, ARTICULATED BLADE
GROSS WEIGHT 8,700 LB., 180-KNOT DESIGN

					(	0	-		-
		EGME	THICK-	FLA!-	TION	WISE	TION	SION	LINE
ACI	HOR	WEIGHT	ES	×	××	X	XXZ	7	X
( .N.)	( .NI )	(18.	Z	-	-	Z	Z	( IN-)	Z
36.0	0	~	.16		2	8	8	4.	7
19.2	7.	6	.33	.2	4	1	1.	6.	.5
302.40	12.16	8	0.233	69.0	0.95	8.19	2.89	2.29	5.62
85.6	5.2	4.	.18	7.	4.	3.9	6.	6.	9
68.8	.2	.2	.15	0	6.	1.0	.2	3	3.0
52.0	.2	.2	.15	-	0	3.8	.5	9.	3.1
35.2	8.2	6.	.16	.2	0	4.0	9.	6.	3.1
18.4	8.2	4.	.16	3	7 .	4.5	1	7.	3.2
01.6	8.2	.5	.17	.3	.2	4.8	8	4.	3.2
84.8	8.2	6.	.17	4.	.2	7.0	7	• 6	3.3
68.0	8.2	6.	.18	Si	.3	7.2	.2	6.	3.3
51.2	~	0	.18	.5	.3	7.8	.2	.2	3.4
34.4	8.2	7	.19	9.	4.	8.5	4.	5	3.4
17.6	8.2	8	119	1.	· S	9.0	5	1	3.5
00.8	18.25	0.	.20	8	•	.5	. 7	0	.5
84.0	8.2	.2	.20	6.	9.	0.0	8	•	3.6
7.2	8.1	4.	.20	7		1.2		4.0	3.7
0.4		2.1	.27	8	0	7.8	• 6	0.0	4.8
3.6	-	9.1	.50	0.0	0	0.0	0.0	5.0	0.0
6.8	-	1.8	.00	0	0.	J	0	0	0
•	7	8	• 00	5.0	0	5.0	5.0	00.0	00.0
2.0	7	D . 1	30.	7.0	•	0.0	•		

TWIST VARIATIONS 0, -4, -8, -16 DEG.

TABLE

(IN.4) 25.40 29.33 00.00 . 83 . 59 4.36 5.32 6.46 .80 14.69 22.25 35.34 9.28 65.76 00.00 SION 19.66 35.00 10.92 12.98 (IN.3) 66.9 11.68 12.49 13.72 17.37 5.00 4.47 7.98 66.6 1.63 3.26 3.69 8.52 9.22 0.77 TION ZYY 4.10 5.84 6.46 5.41 8,700 LB., 180-KNOT DESIGN 45.41 38.30 73.16 4 NI 23.66 27.42 32.21 37.17 57.66 15.21 17.98 92.90 105.80 EDGE-WISE 0.25 82.90 70.00 75.00 65.18 12.61 IYY 5.1 BLADE (IN.3) 3-1 PLANFORM, ARTICULATED 3.12 24.4 40.9 5.00 SEC-TION 1.50 1.94 2.19 2.49 3.70 4.06 4.97 5.46 1.12 1.32 1.71 XXZ DATA H3 HELICOPTER (IN.4) BASIC BLADE FLAT-50.00 75.00 MI SE IXX .90 60. 4.94 5.68 6.53 9.96 1.74 2.12 2.54 3.09 3.69 4.34 7.51 8.71 1.15 11.46 28.51 THICK-(IN.) GROSS WEIGHT 0.210 0.190 0.180 0.170 0.150 0.140 0.130 0.130 0.130 0.120 0.120 0.140 1.500 2.000 NESS .100 MALL 10.99 8.88 8.40 8.27 8.27 8.31 8.53 8.95 9.04 9.16 9.16 SEGMENT 8.22 69.17 WEIGHT (18.) 0-13.-21 14.-61 17.00 18.-21 18.-21 23.-21 23.-21 25.-61 25.-61 26.-81 26.-81 26.-81 27.-61 27. ·NI CHOR 5. 319.20 302.40 285.60 268.80 252.00 235.20 218.40 184.80 151.20 134.40 117.60 100.80 84.00 50.40

-16 UEG • 8 -4. ó THIST VARIATIONS

16.80

39.28

45.66

21.70

16.56 19.05

3.59

AREA (IN.2)

LINE

10.55 12.45 14.41

8.79

24.23

26.99 29.88

32.89 36.03 46.19

41.64

50.00

336.00

RACII (IN.)

BASIC BLADE DATA
H3 HELICOPTER
1-2 PLANFORM, ARTICULATED BLADE
GROSS WEIGHT 8,700 LB., 180-KNOT DESIGN

		CCOVO		01100 5011		05310			
			A		EC	9	U	RO	10
		EGME	I	WISE	-	15	-	NOIS	Z
4	CHORD	<b>WEIGHT</b>	NESS	1 xx	ZXX	IYY	ZYY	, 7	AREA
(IN.)	(IN.)	18.	Z	(IN.4)	•	Z	(IN.5)	(IN.4)	ż
36.0	1.0	.2	.06	.2	0	3.2		.7	.5
19.2	9-0	6.	-12	.5	1.	6.5	4.	.5	9.0
02.4	0.1	. 8	.13		0	5.4	4.	7.43	0
85.6	9.5	4.	+1.	.3	0.	4.1	.2	0	6.9
8.8	18.90	.2	+1.	2.24	1.97	9.	0	.7	5.7
52.0	8.4	.2	.15	-	6.	4.2	4.	6.62	14.77
35.2	7.8	.3	91.	•	1.94	2.7	.2	4.	9
18.4	7.3	4.	.17	0	1.95	1.7	-2	~	12.76
01.6	.1	.5	.18	6.	16-1	0.3	0	8	.7
84.8	-	6.	.20	8	1.86	0.3	7.	•6	9.
68.0	9.	6.	.21	9.	1.80	9.1	0.	.3	8
51.2	7.	0.	.22	Si	1.75	8.0	6.	1.	0.
34.4	9.	1.	.24	+.	1.69	7.0	.8	6.	.3
17.6	-	8	.26	.3	1.64	5.9	9.	.5	Si
00.8	9.	0	.28	2.	1.57	4.7	.5	2	8.
4.0		.2	.30	~	1.47	3.5	4.29	0.	7.
67.20	5.70	7.44	0.330	1.04	1.38	12.65	4-17	3.93	5.44
9.0	4.	2.1	.46	4.	2.00	.3	4-28	4.	0.
3.6	0.	9.1	.50	0.0	15.00	0.0	10.00	5.0	0.0
6.8	0	1.8	00.	5.0	18.00	0	15.00	00.00	0
2.6	0	8	00.	0.	8.0	5.0	15.00	0.0	00.0

THIST VARIATIONS 0, -4, -8, -16 DEG.

TABLE 8-13

BASIC BLADE DATA

AREA (IN. IN. 4 11.54 12.62 6.80 6.80 6.80 7.00 7.80 8.20 8.60 9.40 9.85 31.80 7.40 10.05 10.70 11.11 NOIS 7 (IN.3) 11.20 7.80 8.00 1.20 8.40 .60 8.80 9.15 15.00 6.80 7.08 6.05 6.65 6.95 6.05 6.05 6.05 6.15 TION 3.05 ZYY 180-KNOT DESIGN IYY (IN.4) 31.20 31.70 32.40 32.90 38.60 39.40 40.25 41.20 42.10 44.40 13.25 26.50 54.00 26.50 26.50 80.00 43.10 00.00 EDGE-WISE 1-1 PLANFORM, ARTICULATED BLADE ZXX (IN.3) 5.50 4.00 TION SEC-H4 HELICOPTER GROSS WEIGHT 30,000 LB., IXX (IN.4) FLAT-40.00 1.30 2.60 2.60 2.60 2.72 2.98 3.07 3.57 3.57 4.40 8.50 3.99 4.15 80.00 WISE NESS (IN.) 0.073 0.145 0.145 0.150 0.150 0.165 0.170 0.180 0.185 0.195 THICK . 500 0.205 1.000 0.280 0.210 0.215 MALL SEGMENT 20.70 12.31 12.22 12.13 12.21 11.91 12.10 12.17 12.83 11.97 11.89 11.26 WEIGHT (18.) 19.80 19.80 CHORD 19.80 19.8 9.8 9.8 237.60 216.00 388.80 345.60 259.50 302.40 367.20

16.15 16.20 16.24 16.43

16.50

16.56 16.62 16.70

16.10

15.90 15.98

15.90

15.90

LINE -01H

15.90

DEG. 8-DESIGN THIST

-16 DEG.

-4, -8,

THIST VARIATIONS O.

30.00

16.75

16.82 17.93

TABLE 8-14

8.20 8.60 9.40 9.40 4.50 20.05 31.80 31.80 50.00 7.00 7.40 SION .63 F.NI) (ENI) 9.15 6.80 7.08 8.00 8.20 8.40 6.80 1.63 6.95 8.60 TION 3.61 4.82 6.05 6.15 6.65 GROSS WEIGHT 30,000 LB., 180-KNOT DESIGN (IN. d) 2.47 **26.80 31.20** 31.70 80.00 10.61 32.90 39.40 26.50 44.40 38.60 40.25 41.20 42.10 43.10 54.00 WISE IYY N.L. PLANFORM, ARTICULATED BLADE ZXX ( S.N.) .70 1.17 1.20 2.30 2.45 2.50 2.53 2.80 3.00 TION 111 3.20 5.50 4.00 SEC-0.57 3.50 BASIC BLADE DATA H4 HELICOPTER IXX (IN.4) FLAT-1.68 2.42 2.98 3.00 3.00 3.40 3.40 4.99 WISE 4.40 8.50 0.17 0.93 0.00 THICK-(IN.) 0.163 0.327 0.183 0.185 0.165 0.170 0.175 0.175 0.175 0.175 0.195 0.205 0.205 0.215 NESS 000 .500 WALL SEGMENT 12.31 12.22 12.22 12.21 12.21 12.17 12.83 12.83 11.97 11.97 11.26 16.53 WE IGHT (18.) 6.60 13.20 16.50 19.80 19.80 19.80 19.80 19.80 8.84 CHORD

6.80 11.59 15.90

3.05

AREA (IN.

MIO-

10.15

15.98

16.20

16.43

15.50

16.56

TWIST VARIATIONS O. -4. -8, -16 DEG.

30.00

00

17.93

15.82

16.70

16.75

410.40

432.

RADII (IN.) 388.80 345.60 345.60 302.40 280.80 259.20 237.60 194.40 172.80 151.20

86.40

108.00

TABLE 8-15

17.39 22.57 25.56 28.74 31.98 AREA (IN.2) LINE 23.68 34.86 1.65 4.13 4.99 5.84 10.45 12.53 14.85 17.45 50.00 SION 3.31 00.00 IN. .81 30.74 20.38 (IN.3) 15.08 16.18 60.4 TION ZYY 5.09 5.09 5.53 7.31 8.57 11.37 12.25 9.23 2.04 13.17 14.11 GROSS WEIGHT 30,000 LB., 180-KNOT DESIGN IVY (IN.4) 92.68 .80 19.62 22.87 26.80 16.14 6.36 71.96 115.50 45.10 199.70 80.00 36.16 41.36 54.73 81.70 EDGE-WISE 128 3-1 PLANFORM, ARTICULATED BLADE ZXX (IN.3 14.00 SEC-TION 69.0 .38 2.29 4.19 69.4 61.9 7.58 3.52 5.17 5.63 6.77 .60 99. .95 .21 16.93 .81 BASIC BLADE DATA H4 HELICOPTER (IN.4) FLAT-13.41 10.27 40.00 WI SE 0.60 1.20 5.30 6.64 9.06 11.78 1.87 2.22 2.72 3.38 4.57 36.25 IXX WALL THICK-(IN.) 1.000 0.136 0.133 0.129 0.127 0.122 0.122 0.153 0.149 0.144 0.140 0.184 NESS 0.167 -102 0.147 SEGNENT 11.97 11.61 11.89 12.74 11.26 20.70 12.31 12.22 12.21 12.21 12.17 12.83 12.88 16.53 .92 3.56 74.74 **WEIGHT** (LB.) 14.50 17.30 18.50 19.80 21.20 23.75 25.10 26.45 27.80 29.20 33.00 16.00 (IN.) CHORD 16 172.80 151.20 129.60 64.80 345.60 259.20 •20 86.40 108.00 194.40 367.20 302.40 280.80 216.00 432.00 410.40 388.80 (IN.) RADII

12.83

15.01

10.64

20.06

8.54

DEG. 91--8, -4. THIST VARIATIONS O.

50.68 55.20 58.38 30.00 00.00

35.48 39.32 42.76 46.62

TABLE 8-16

BASIC BLADE DATA
H4 HELICOPTER
1-2 PLANFORM, ARTICULATED BLADE
GROSS WEIGHT 30,000 LB., 180-KNOT DESIGN

MID- LINE AREA (IN.2)	10.95 21.91 20.83 19.33	00000		7.18 6.28 4.23 30.00
10R- SION J	המיחים	00004	6.26 6.17 5.77 5.58	84800
SEC- TION 2YY3 (IN-3)	3.36 6.72 6.30 6.14	94440	6.57 6.30 6.30 6.18 5.95	74000
EDGE- WISE IYY (IN. 4)	977.6	28.68.0	25.67 25.69 23.63 22.51 20.92	9.00
SEC- TION ZXX (IN.3)	1.25 2.51 2.43 2.33 2.25	2662-	2.23 2.24 2.08 2.08	8,000
FLAT- WISE IXX (IN.4)	96101	0004	2.24 2.20 2.01 1.91	24400
WALL THICK- NESS (IN.)	06 13 13 14 15	161.19	0.222 0.234 0.253 0.269	46.000
SEGMENT WEIGHT (LB.)	22.3.7	2.2	12.83 12.83 11.97 11.61	3.9
CHORD (IN.)	90460	9.00	16.80 16.80 15.70 15.25	4.09.5
RADII	32.0 10.4 88.8 67.2	24.0	237-60 216-00 194-40 172-80 151-20	08-0 86-4 64-8 43-2 24-0

THIST VARIATIONS O. -4. -8. -16 DEG.

PRECONE ANGLE

DEG

TABLE 8-17

BASIC BLADE DATA HI-R HELICOPTER 1-1 PLANFORM, RIGID BLADE GROSS WEIGHT 12,000 LB., 150-KNOT DESIGN

			AL	FLAT-	w	90			-0 I W
		EGME	THICK-		TION	WISE	TION	SION	LINE
ADI	CHORD	-	ES	IXX	×	>	>	, 7	
	(IN.)	(18.	Z		-			(IN. +)	ż
72.0	8.2	S	.07	6.		0.1	5	8	4
53.4	8.2	S	.14	6.	8	0.3	0	.5	6.
34.8	8.2	9.5	.14	6.		0.5	0	.7	5.9
16.2	8.2	1.	.14	6.		9.0	0.	6.	6.
91.6	8.2	7	-14	0		0.8	1.	0.	6.
79.0	9.2	.2	.15	2.04	1.90	0.9	1.	.3	0
260.40	18.25	9.03	0.154		•	23.70	5.50	6.60	13.10
44.8	1.2	1.	.15	2.19	0	4.0	• 6	8	
29.2	8.2	4.	-16	.2	1.	4.3	.5	0.	.2
9.40	8.2	.3	-16	2.35	.2	4.8	8	.3	.2
86.0	8.2	6.	.17	2.45	.2	7.0	7.	• 6	.3
67.4	8.2	6.	.18	5	.3	7.3	.2	6.	.3
48.8	8.2	0	.18	2.60	6	8.0	.2	.2	4.
30.2	8.2	1.	•19		4.	8.5	4.	.5	4.
11.6	8.2	1	•19	2.80	.5	9.3	.5	0	.5
3.0	18.25	0.	.20	6.	9.	9.8	1.	6.	.5
4.4	-	Si	.21	3.04		0.5	6.	4.0	3.6
5.8	8.10	0.5	.26	4.40	3.60	5.0	6.	0	
37.20	.1	.2	00.	0	0	6.0	0	0.0	0.0
18.60	1.	4.1	00.		0.	6.0	0.	0.0	00.0
12.63	8.10	9.0	00.	0	•	6.0	0	000	0.0

## BEARING FLEXIBILITY 9 MILLION IN. LB. PER RAD.

TABLE 8-18

BASIC BLADE DATA H1-R HELICOPTER N.L. PLANFORM, RIGID BLADE GROSS WEIGHT 12,000 LB., 150-KNOT DESIGN

TOR- MID- SION LINE J AREA IN-4) (IN-2)	.48 1.2 .96 2.5 .20 5.6	90 9.6 00 12.9 30 13.0	.80 13.1 .00 13.2 .30 13.2	20 13. 50 13. 50 13.	13.6 14.1 50.0 100.0
SEC- TION ZYY (IN. <sup>3</sup> ) (	200	8 1	U O N B -	6.20 6.20 6.58 6.58	260000
EDGE- WISE IYY (IN. 4)	8 - 1	7.00	- O M B C	27.30 28.00 28.50 29.30	00000
SEC- 110N 2XX (1N.3)	0.22	4000	2046	2.30 2.30 2.50 2.50	~ 9000
FLAT- NISE IXX (IN.4)	0.12		NM		0 4 0 0 0
WALL THICK- NESS (IN.)	32	71.51.	51.5	0.180 0.186 0.191 0.202	12,000
SEGMENT WEIGHT (LB.)	NNN	777	0440	9.94 10.01 8.73 9.06	N N N N N
CHORD (IN.)	2.1	222		18.25 18.25 18.25 18.25	8 8 8 8
RADII	72.0 53.4	16.2	410 411 23 23 24 25 25 25 25 25 25 25 25 25 25 25 25 25	168-40 168-40 130-20 111-60	46764

BEARING FLEXIBILITY 9 MILLION IN.LB. PER RAD.

PRELAG ANGLE -11.7 DEG. AT -4 DEG THIST PRECONE ANGLE 3.18 DEG.

THIST VARIATIONS 0, -4, -8, -16 DEG.

TABLE 8-19

BASIC BLADE DATA H1-R HELICOPTER 3-1 PLANFORM, RIGID BLADE GROSS WEIGHT 12,000 LB., 150-KNOT DESIGN

			AL	_	ш	9	SEC-	TOR-	MID
		EGNE	THICK-	WI SE	TION	WISE	TION	SION	LINE
AD	HOR	-	ES	×	××	7	X	7	AREA
(IN.)	CIN.	(18.	Z	-	-	Z	H	(IN.)	Z
72.0	2.2	5	01.	•	0.56	7.	9	4.	•
353.40	13.50	12.57	0.200	0.91		10.34	3.29	2.78	7.3
34.8	4.7	9.5	.18	•	1.31	8	1.	5	•
16.2	6.0	~	111	•	.5	5.4	10	6.	0
91.6	7.2	7.	.16	•	9.	8.2	.5	.2	•
79.0	8.4	.2	.15	2.11	8.	1.5	6.	.2	5.
4.09	9.5	0	11.	2.45	1.	7.3	8.	5	9
41.8	0.8	7.	11.	2.94	.3	1.5	.2	0	6
23.2	2.0	4.	.13	3.54	9.	6.3	8	4.0	•
9.40	3.2	.3	.13	4.10	6.	1.6	4.	.2	4.
86.0	4.4	6.	.13	4.82	.2	0.5	4.	4.2	7.
67.4	5.6	6.	.13	•	9.	7.0	0.	9.9	0
48.8	6-8	0.	.12	.2	6.	3.4	1.	8.7	2.
30.2	8.0	.7	.12	7.43	4.	3.1	0.7	2.0	9
11.6	9.2	.7	.12	5	8	3.5	1.8	5.4	6
3.0	0.4	0	.12	6.	4.	4.1	2.6	0.2	2.
4.4	4.1	.5	.12	1.5	0.	6.9	3.7	4.3	9
5.8	4.7	0.5	114	7.7	6.	9.9	5.8	1.3	6
7.2	4.7	5.2	.00	5.0	0	8.0	0	0.0	0
8.6	4.7	~	00.	30.00	18.00	8.0	5.0	00.00	0
2.6	4.7	0.4	.00	0.0	18.00	8.0	15.00	0.0	00

BEARING FLEXIBILITY 10 MILLION IN.LB. PER RAD.

PRELAG ANGLE -13.0 DEG. AT -4 DEG TWIST CONE ANGLE 3.45 DEG.

-8, -16 DEG.

TMIST VARIATIONS 0, -4.

TABLE 8-20

BASIC BLADE DATA HI-R HELICOPTER 1-2 PLANFORM, RIGID BLADE GROSS WEIGHT 12,000 LB., 150-KNOT DESIGN

			A	FLAT-	W	90	W	_	
		EGNE	THICK-	WISE	TION	HISE	TION	NOIS	LINE
	CHORD	WEIGHT	ES	IXX	×	>	77	7	
( .NI )	(IN.)	(18.	Z	(IN.4)	-			(IN. 2)	Z
72.0	1.0	5	.06			5.9	1.	3.58	.3
53.4	20.40		.12	2.50	0	25.80	5.40	-	18.72
34.8	9.8	9.5	.13			4.4	.2	.8	.5
16.2	9.3	7	.13	•		3.2	1.	.6	16.56
97.6		-	+1.			2.1	0.	4.	15.61
79.0	4	.2	.15	2.08			6.	.2	14.87
4.09		0	.15			22.44	.2		13.74
41.8		1.	.16	•			7.	0	12.83
223.20	16.70	9.45	0.180	1.84	1.84	19.96	4.94	5.63	
9.40	.2	6	.19			0.		4.	10.93
86.0		6.	.20			19.22		.2	10.05
4.E	15.20	6.	.22		1.72	•	4.86	0.	.2
9.9	9.	0.	.23	4.		16.77	1.	1	8.36
130.20	7		.25		1.60	15.66	.5	4.50	7.61
1.6	9.	.7	.27	7	1.53	14.68	4.50	4.23	6.88
0	0,	0	.30	1.	1.42	13.24	4.23	6.	6.03
4.4	Si	S	.32	0	1.33	12.15	40.4	3.63	5.35
5.8	.5	0.5	44.	0.	1.4%	11.67	4.12	8	4.27
37.20	5.00	55.21	90.	2.00	14.00		10.00	0.0	0.0
18.60	0	4.1	90.	0.0	18.00	0.0	15.00	100.00	100.00
12.63	9	4.0	00.	0.	18.00	80.00	12.00	000	0.0

BEARING FLEXIBILITY 10 MILLION IN.LB. PER RAD.

PRELAG ANGLE -12.2 DEG. PRECONE ANGLE 3.00 DEG. AT -4 DEG TWIST

-4. -8, -16 DEG.

THIST VARIATIONS O.

TABLE B-21

BASIC BLADE DATA H2-R HELICOPTER 1-1 PLANFORM, RIGID BLADE GROSS WEIGHT 33,000 LB., 150-KNOT DESIGN

			AL	_	EC	9	ن	TOR-	01
		EGME	THICK-	WISE	TION	15	ō		Z
10	CHORD	WEIGHT	ES	×	×	X			04
IN	(IN.)	(18.	Z	-	-	(IN. 1)	(). NI)	Z	Z
2	4	0	80	00	3	9.6	8	6.	5
1	7	4	19	1	0	9.8	8	2.7	3.2
	7		8	~	7	2.9	5	5.0	
47.20	23.65	15.77	0.204	4.75	3.62	53.00	9.80	14.90	19.73
9.57	3.6	5.7	21	0	8	5.3	.2	6.5	9.8
9	3.6	7-1	.21	4	1.	4.8	1.3	8.0	0.1
32.4	3.6	0.2	.22	S	2	5.3	4.	0.6	0.1
80.8	3.6	7.6	.22	9.	CI	6.0	• 6	9.3	0.2
59.2	3.6	7.0	.22	8	6	6.8	11.70	1.6	0.2
37.6	3.6	8.0	.23	6.	4.	7.3	1.9	0.0	0.2
16.0	3.6	7.7	.23	0	4.	8.0	2.0	0.3	0.3
7 70	3.6	9-9	.24	-	5	8.8	2.1	0.7	0.3
72.8	3.6	4-9	-24	.2	9.	9.3	12.30	21.05	4.0
51.2	3.6	6.4	.24	4	1	0.1	2.4	1.4	9.0
20.6	3.6	7.3	.25	4	6	2.0	2.8	1.8	0.5
0.80	6	8.4	- 29	7	8	0.8	4.3	3.4	1.0
B.K.			37	0.0	0	4.0	2.2	8.8	4.6
4		7 7	00	0.0	0	3.0	0.0	00.00	00.0
		7	00	0.0	0	43.00	0.0	0.0	0.0
		4	00.	0	0	3.0	0.0	50.0	100.00
	,		)						

BEARING FLEXIBILITY 20 MILLION IN.LB. PER RAD.

PRELAG ANGLE -6.7 DEG. AT 0 DEG DESIGN TWIST PRECONE ANGLE 4.3 DEG.

THIST VARIATIONS O. -4, -8, -16 DEG.

BASIC BLADE DATA H2-R HELICOPTER N.L. PLANFORM, RIGID BLADE GROSS WEIGHT 33,000 LB., 150-KNOT DESIGN

			AL	LA	W	90	u	TOR-	MID
		EGME	I		-	IS	TION	SION	LINE
ADI	HOR	16H	ESS	××	×	Y	77	7	AREA
(IN.)	(IN.)	(18	(IN.)	(IN.4)	(IN.3)	(IN.4)	(IN.5)	(IN.A)	(IN.2)
32.	8	6	. 18	•	(		1.59	-	7
10.	1.8	9.6	.36	5				N	2
388.80	15.76	14.51	0.287	1.51	1.60	17.13	5.30	5.34	8.98
64.	9.7	5.7	.24	0.	•	•		9	6.4
\$	3.6	5.7	.21	0.	.8	5.	.2	6.5	8
24.	3.6	7.1	.21	4.	7.	4.	1.3	0	0.1
02.	3.6	0.2	.22	.5	.2	5.	1.4	0	0.1
80.	3.6	7.6	.22	9.	-2	.9	1.6	9.3	0.2
59.	3.6	0.	.22	8	.3	9	1.7	9.7	0.2
B	3.6	8.0	.23	6.	4.	1.	1.9	0.0	0.2
16.	3.6	7.7	.23	0	4.	8	2.0	0.3	0.3
3	3.6	•6	.24	7.	.5	8.	1.	~	0.3
73.	9.6	4.9	.24	.2	9.	6	2.3	1.0	4.0
3	3.6	4.9	.24	4.	1.	0	2.4	1.4	4.0
29.	3.6	7.3	-25	4.	6.	2.	2.8	1.8	0.5
08.	1	18.46	.29	-	8	0	4.3	3.4	1.0
	1	8.1	.37	0.0	0	4.	2.2	8.8	4.6
•	1	4.6	• 00	0.	0	3.	0.0	0.0	0.0
	1.	7.1	00.	0.0	0		0.0	0.0	0.0
•	.7	.5	00.	0	0	43.00	0.0	150.00	0.00

BEARING FLEXIBILITY 20 MILLION IN.LB. PER RAD.

THIST VARIATIONS 0, -4, -8, -16 DEG.

-5.47 DEG.

PRELAG ANGLE

IE ANGLE 4.3 DEG. AT -8 DEG THIST

TABLE 8-23

BASIC BLADE DATA H2-R HELICOPTER 3-1 PLANFORM, RIGID BLADE GROSS WEIGHT 33,000 LB., 150-KNOT DESIGN

			AL		ш	5		TOR-	]
		EGME	H	-	-	S	-	SION	
ADI	CHORD	WEIGHT	NESS	1XX	ZXX	IYY	Z	7	AREA
CIN		(18.	Z	-	-	Z	().NI		Ž
9	0	Q	-	Œ	00	0.1	8	6.	
26.0	0 4	7	100	7	-	7	5.64	5.90	1.6
• • •		7.0	ייי	. 4	-	9-9	1	.3	4.0
8.8	7	Ū,	200	7	1	6	9	9.	3
2-19		- 1	7	J .	. (		0	7 7 7	9.1
15.6	0.2	2.1	77.	À.	,				
24.0	7.5	1-1	.21	1	20		• •		, (
32.4	6	3.2	.20	•	e.	9.9	3.6	\$ ·	9 6
80	8	7.6	119	9	1	9.9	4.7	B • C	7.6
200		7.0	119	(1)	0	2.9	5.3	6-2	0
37.6		8	18	4.0	1	13.	0.7	4-1	7.4
		7	1	1.5	.2	27.6	8.3	9.1	8-1
	•	,		3.6	8	43.	9.6	6.3	5.6
			-	3		55.	0.5	8.2	6.6
08.71	04.40	74 97	0.157	17.31	7.93	177.70	22.23	56.03	(4)
7.10		0 6	-	0	4	00	3.8	2.4	1.6
29.67			-		, -	44	8	7.4	4.9
08.0	9	9	77.	•	•	,		70	7 - 6
9-9	9	8.1	1.	2.	•	20.	*		
7	4	4.1	0	0	13.00	4.	0.0	•	0.0
		77	5	0	-	4.	0.0	50.0	00
0	•		6		-	7	10.00	50.0	0.00
4.	9	•	5	•	00.61	•	•		

BEARING FLEXIBILITY 15 MILLION IN.LB. PER RAD.

PRELAG ANGLE -5.9 DEG. AT -8 DEG TWIST PRECONE ANGLE 4.4 DEG.

THIST VARIATIONS 0. -4. -8. -16 DEG.

BASIC BLADE DATA H2-R HELICOPTER 1-2 PLANFORM, RIGID BLADE GROSS WEIGHT 33,000 LB., 150-KNOT DESIGN

			AL	FLAT-	ш	90	SEC-	TOR-	-0 I W
		EGME	THICK-	WISE	TION	WISE	10	SION	Z
ADI	HOR	WEIGHT	ES	IXX	×	1	2 Y Y Z	7	AREA
(IN.)	( IN. )	(18.	Z	(IN. 1)	-	Z		(LN-)	Z
32.0	7.0	6	.07	4	5	5.1	.5	7.48	4.6
10.4	6.4	9.6	+1.		0	3.2	-	6.4	6
8.8	5.7	4.5	.16	0	7	1.2	.6	9	7.5
54.5	5.0	5.7	.19		•	9.8	0.9	8	5.5
45.6	4.4	5.7	.20	4.	1.	9.2	1.2	8	4.1
6.0	9.	7.1	.21		.8	4.5	12.38	18.91	22.16
02.4	2.9	0.2	.22	-	1.	7.0	2.0	1.	9.0
80.8	2.3	7.6	.23	6.	.6	7.8	1.7	7.0	6.3
59.2	1.6	7.0	.25	9.	.5	4.4	1.4	1.9	4.9
37.6	1.0	8.0	.26	4.	.5	1.3	1.1	5.5	1.9
16.0	0.3	7.7	.28	0	.3	6.2	0.8	4.4	5.4
94.4	9.6	9.9	.29	1	.2	4.6	4.	3.4	4.1
72.8	8.9	4.9	.31	4.	0.	1.1	0.0	2.4	•
51.2	8.2	4.9	.33		8	7.8	9.58	1.5	1.6
29.6	7.5	7.3	.36		9.	5.1	7.	0.5	•
0.00	7.0	8.4	.43	•	6.	5.0	Si	0.5	0.3
86.4		8.1	.71		9.	8.0	9.	3.9	4.1
4.8		4.6	00.	0	•	0.0	0.0	000	00.00
m	1	77.12		10.00	1.00	00.09	10.00	150.00	100.00
24.00	6.70	S	0	0	0	0.0	0.0	50.0	100.00

BEARING FLEXIBILITY 15 MILLION IN-LB. PER RAD.

PRELAG ANGLE -5.95 DEG. AT -8 DEG THIST ANGLE 4.1 DEG. PRECONE

THIST VARIATIONS 0. -4. -8, -16 DEG.

TABLE 8-25

BASIC BLADE DATA H3-R HELICOPTER 1-1 PLANFORM, RIGIO BLADE GROSS WEIGHT 8,700 LB., 180-KNOT DESIGN

			AL	FLAT-	W	90	EC	TOR-	
		EGME	THICK-	WISE	TION	WISE	TION	2	LINE
ADI	HOR	WEIGHT	ES	IXX	×	7	7	7	RE
(IN.)	(IN.)	(18.	Z	(IN.4)	-	(IN.4)	( ).NI)	( .NI )	ż
36.0	8-2	~	07	0	0	0.3	N	6.	
19.2	8.2	6	77.	0	8	0.5	0	6.	•
02.4	8.2	8.8	14	0	8	7.0	1.	0.	
85.6	8.2	4	.15		6	6.0	7.		13.00
268.80	18.25	8.27	0.153	0	1.92	21.00	5.20	6.30	3.0
52.0	8.2	7	.15	-	0	3.8	5	9.	•
35.2	8.2	3	116	7	0	4.0	9.	9.30	3.1
10.4	8.2	4	.16	2.30	7	4.5	1	1.	3.2
01-6	8.2	5	.17	.3	.2	4.8	.8	7.40	3.2
84.8	8.2	6	.17	4	-2	7.0	1.	9.	3.3
68.0	8.2	6	.18	5	6	7.2	.2	6.	3.3
5.1.2	8.2	0	.18	S		7.8	.2	.2	3.4
34.4	8.2	7	.19	9.	4.	8.5	4.	3	3.4
17.6	8.2	8	.19	1	S	9.0	S	.7	3.5
00.8	8.2	0	.20	8	9.	9.5	1.	0	e,
84.0	8.2	.2	.20		.6	0.0	.8	•	• 6
7.2	8.1	4	.21	3.10	1	1.2	7	4.0	.7
0.4	7	2.1	.27	0	0.	3.0	0	0.0	
3.6		9.1	.50	0	0	3.0	0.	5.0	0.0
6.8		1.8	00	5.00	0	3.0	0	0	0
2.6		8	00.	0	0	3.0	0	00.0	0.0
	)								

BEARING FLEXIBILITY 9 MILLION IN. LS. PER RAD.

PRECONE ANGLE 2.45 DEG. AT 0 DEG DESIGN THIST PRELAG ANGLE -10.7 DEG

THIST VARIATIONS O. -4, -8, -16 DEG.

TABLE B-26

BASIC BLADE DATA

			43-	HEL IC	ER TO BI ADE				
		GROSS	(	,700 LB., 18	~	T DESIGN			
			WALL	FLAT-	SEC-	EDGE-	SEC-	TOR-	-01W
		SEGMENT	THICK-	WISE	LION	WISE	110N	NOIS	LINE
RADII	CHORD	E16H	NESS	IXX	Zxx -	IYY	277	, 7	AREA
	( IN )	(18.)	( IN.)	(IN.4)	(IN.3)	(IN.*)	(IN.3)	(IN.4)	(IN.2)
36.0	0	.2	191.0	0.12	0.22	1.87	0.89	0.49	1.25
19.2	7	•	0.332	0.24	94.0	3.73	1.11	0.99	
02.4	2.1	8	0.233	69.0	0.95	61.8	2.89	2.29	5.62
285.60	15.20	8.40	0.184		1.42	13.94	3.91	3.98	•
68.8	8.2	.2	0.153	2.06	1.92	21.00	5.20	6.30	13.00
52.0	8.2		0.155	٦.	2.00	23.80	5.50	6.65	13.12
35.2	8.5		0.160	•	2.03	24.00	5.60	6.90	13.16
18.4	8.2	*	0.165	2.30	2.14	24.50	5.70	7.10	13.20
9.10	8.2	Š	0.170	2.38	2.20	24.80	5.80	7.40	13.25
84.8	8.2	٥.	0.175	2.47	2.26	27.00	6.10	7.65	13.35
68.0	8.2	•	0.180	•	2.30	27.25	6.20	7.90	13.38
51.2	8.2	•	0.185	2.59	2.36	27.80	6.20	8.25	13.40
34.4	8.2	7	0.190	•	2.40	28.50	04.9	8.50	13.45
17.6	8.2	8	0.195	2.78	2.50	29.00	6.50	8.70	13.50
00.8	8.2	•	0.200	2.88	2.60	29.50	6.70	00.6	13.55
•	8.2	7,	0.206	2.97	2.65	30.00	6.80	09.6	13.60
	7	7.4	0.203	•	2.75	31.20	7.10	;	13.72
*	7	2.1	0.273	•	3.00	23.00	00.9	20.00	14.85
•	₹	9.1	1.500	ó	3.00	23.00	00.9	35.00	50.00
8	7	8	2.000	2.00	3.00	23.00	00.9	100.00	100.00
•	-	4.8	2.000	2.00	3.00	23.00	00.9	100.00	100.00

BEARING FLEXIBILITY 9 MILLION IN. LB. PER RAD.

PRELAG ANGLE -9.14 DEG. AT -4 DEG TWIST PRECONE ANGLE 2.4 DEG.

THIST VARIATIONS 0, -4, -8, -16 DEG.

TABLE 8-27

(IN.4) 22.25 3.59 5.32 7.80 10.92 12.98 9.66 2.83 4.36 9.49 9.28 SION 14.69 17.15 (IN.3) 66.9 7.98 6.46 8.52 66.6 •63 4.10 25 --5.84 9.22 TION 3.26 69. ZYY 5.41 10.77 8,700 LB., 180-KNOT DESIGN 1YY (IN.4) 73.16 82.90 17.98 23.66 27.42 32.21 37.17 57.66 65.18 51.04 5.13 12.61 15.21 45.41 EDGE-WISE 10.25 PLANFORM, RIGID BLADE (IN.3) 2.19 2.49 2.79 3.12 3.38 3.06 4.47 .50 .19 1.32 SEC-TION .71 XXZ BLADE DATA H3-R HELICOPTER MISE IXX (IN.4) FLAT-6.53 0.45 2.54 46.4 3.69 4.34 5.68 1.15 1.74 7.51 BASIC THICK-WEIGHT (IN.) 0.210 0.190 0.180 0.170 0.150 0.140 0.130 0.120 0.120 0.120 0.120 NESS .100 HALL 3-1 GROSS SEGNENT 16. 7.85 8.88 8.24 8.24 8.31 8.53 8.53 9.16 8.97 10.99 .27 WEIGHT (18.) 14.60 15.80 17.00 18.20 19.40 20.70 22.00 24.40 26.80 28.00 29.20 30.40 14.50 15.00 12.20 13.40 (IN.)

7.18 8.79

·S.

AREA (IN.2

つ

CHORD

RADII (IN.)

LINE HID-

24.23 26.99

29.88 32.89 36.03 39.28

21.70

14.41 16.56 19.05

10.55 12.45 45.66

46.19

29.33

11.68 12.49 13.72 10.00

92.90 105.80

4.97 5.46 40.9

8.71

11.46 28.51

7.44

1117-60 100-80 84-00 67-20 50-40

69.17

12.19

8.22

40.14 50.00 00.00 00.00

65.76

35.00

10.00

.00 00.

10.00

00.

14.48 15.00 15.00

30.00

000.

4.80

71.84

5.00

00.00

00.00

-11.12 DEG.

PRELAG ANGLE

-4 DEG THIST

AI

2.75 DEG.

ANGLE

PRECONE

RAD. PER FLEXIBILITY 10 MILLION IN-LB. BEARING

225

252.00

302.40 319.20

336.00

285.60

235.20 218.40 201.60

184.80 168.00

151.20

TABLE 8-28

BASIC BLADE DATA
H3-R HELICOPTER
1-2 PLANFORM, RIGID BLADE
GROSS WEIGHT 8,700 LB., 180-KNOT DESIGN

MID- LINE AREA (IN-2)	9.54 19.09 18.08	5.7	9174	0000	6.13 6.13 50.00 100.00
SION	3.78	07.9	4-84	5 to 10 to 10	3.5.00 3.93 35.00 100.00
SEC- FION ZYY (IN.3)		404	200-		10.00
EDGE- NISE IVY (IN.4)	13.29 26.58 25.48	4.6	ててるる	0000	13.57
SEC- TION ZXX (IN.3)	1.05 2.10 2.07	000	1.95		2.00.00.00.00.00.00.00.00.00.00.00.00.00
FLAT- WISE IXX (IN.4)	1.29 2.59 2.50	W. 4	2.07 2.02 1.91	0 W 4 W C	1.15 1.15 1.04 8.00 8.00
WALL THICK- NESS (IN.)	.12	41.	91.	22223	0.305 0.302 0.330 0.462 2.000 2.000
SEGMENT WEIGHT (LB.)	700	444	4400	00 m 00	8.22 7.44 12.19 69.17 71.84
CHORD (IN.)	0.0	8.9	6.7	4.6	14.00 14.00 14.00 16.00
RADII	36.0 19.2 02.4	85.6 68.8 52.0	35.2	9044	84. 64. 33. 116.

BEARING FLEXIBILITY 10 MILLION IN-LB. PER RAD.

THIST VARIATIONS 0. -4" -8, -16 DEG.

AT -4 DEG THIST PRELAG ANGLE -10.12 DEG.

PRECONE ANGLE 2.3 DEG.

4.35 DEG. AT -4 DEG DESIGN THIST PRELAG ANGLE -10.1 DE THIST VARIATIONS 0, -4, -8, -16 DEG.

PRECONE ANGLE

9
2
1
8
w
8
4
-

BASIC BLADE DATA H4-R HELICOPTER 1-1 PLANFORM, RIGID BLADE GROSS WEIGHT 30,000 LB., 180-KNOT DESIGN

			MAN		W	90		TOR-	-014
		CCNC		FILSE	TION	WISE	TION	SION	LINE
•		SEGREN.	2004		×	IYY	ZYY	7	AREA
2	202		)	-		2		TNI	( IN L
( . z . )	( . N . )		Z		-		4		
	•	·		4	-	3.2	_	4.	15.90
12.0	3.8	Ú		7	4 (	, ,	•	a	0
4-0	8.6	7.1	14	9	7	6.5	5	•	1
	4		14	9	7.	6.5	Ó	6.80	7
7 0 0				9	7	6.5	0	8	9
V - 10	•	-			~		0	7.00	15.90
0.0	0 .		1	1	ור	8 9	-	7.40	9
24.0	9.8	7 . 7	07	•	•	, ,	1	Œ	
32.4	9.6	6.1	.16	8	1	7.1	0	•	•
	0	1 7	.17	6	4.	1.7	8	7	7 .0
00.007	00.01	12.17	0.175	3-00	2.50	32.40	6.95	8.60	
7.60		• 6			5	2.9	0	9	6.2
37.0	0 . 0	1	0 7 0	•	) @	8	8	4	9
16.0	9 . 6	2 - 7	01.	•	•	4		a d	6.5
94.4	9.8	2.8	61.	0	•	7 (	, (		5
72.8	9.6	5-1	61.		-	7.0			1
51.2	9.6	1.6	.20	3.83	7	1.2	4.	•	70.01
20	9.6	1.8	.20	6.		45.10	9.		- 1
9	0	0	.21	-	•	43.10	8	• 1	
			2	4		44.40	-	12.62	16.82
4.0	~	1	7	•				1	17.93
4.8	<b>~</b>	9	.28	0.0	00.01	7	•		30 06
3.2	~	4.	9	20.00	2.6		•	000	
4		3.	.50	0.0	15.00	5.0	7.00	100.00	00.001
•									

## BEARING FLEXIBILITY IS MILLION IN. LB. PER RAD.

BASIC BLADE DATA
H4-R HELICOPTER
N.L. PLANFORM, RIGID BLADE
GROSS WEIGHT 30,000 LB., 180-KNOT DESIGN

			WALL	FLAT-	L	DC	ü		
		GME	I	WISE	-	S	TION	NOIS	
RADII		EIG	W		×	1 7 7	7		u
(IN.)	(IN.)		Z	(IN.4)	(IN.3)	(IN. 4)	. 2	4.N.	(IN.2)
32.0	•	S	.16	0-17	C	7	4	ď	ď
10.4	•	0.7	.32	0.34	5	0		-	•
8.88	3.	2.3	.22	0.93		0.6	9	1 4	• a
367.20	•	.2	. 18	1.68	1.70	7.7	00	, v	11.59
45.6	9.	2.1	-15	9.	.2	6.5	0	10	0
24.0	6	2.2	•16	1.	.3	6.8	7	4	0
02.4	9.	1.9	.16	8	4.	1.2	9.	8	
80.8	6	7.	11.	6.	4.	1.7	8	.2	6.1
59.2	6	2.1	.17	0.	5	2.4	6	9	
37.6	•	2.3	.18	3.07	.5	2.9	0	0	6.2
16.0	9.	2.8	.18	+.	.8	8.6	8	4	14
4.4	6	2.8	•10	.5	6.	9.4	0.	8	6.5
72.8	6	1.9	•18	-	0.	0.2	.2	0	6.5
51.2	6	1.6	.20		7.	1.2	4.	0.7	9.9
9.6	6	1.8	.20	3.99	.2	2.1	9.	1.	6.7
8.0		2.7	.21	4.15	.3	3.1	8	5	6.7
6.4	•	1.2	.21	4.40	.5	4.4	7.	2.6	6-8
4.8	•	6.5	.28	0.0	10.00	5.0	7.00	1.8	6
43.20	8.84	74.74	7	50.00	0	5.0	0	0	0
4.0	•	3.9	.50	50.00	15.00	35.00	•	0	100.00

BEARING FLEXIBILITY 15 MILLION IN.LB. PER RAD.

PRELAG ANGLE -6.99 DEG. AT -4 DEG THIST PRECONE ANGLE 3.6 DEG.

THIST VARIATIONS O. -4. -8, -16 DEG.

TABLE 8-31

BASIC BLADE DATA H4-R HELICOPTER 3-1 PLANFORM, RIGID BLADE GROSS WEIGHT 30,000 LB., 180-KNOT DESIGN

			4	FLAT-	W	90	SEC-	TOR-	MID
		EGME			TION	MISE	TION	NOIS	LINE
ADI	CHORD	16	ES	IXX	×	7	ZYY	7	AREA
(IN.)	(IN.)	(18.)	-	(IN.4)	(IN.G)	Z	(IN.3)	(IN. 4)	(IN.2
32.	13.40	5	.10	09-0		6-61	2.04		4.2
410.40	N	20.70	0.204	1.20			4-03	3	5
88.	5.9	.3	.18	1.53	9	6.3	9		_
67.	7.3	2.2	.17	1.87	8		0	6.	0
5	8.5	2.1	116	2.22	0	0	5	8	5.0
24.	9.8	2.2	•16	2.72	.2			7.13	7.3
05.	1.2	1.9	•15	3.38	9.	36-16	7.31	8.81	0
8	2.4	2.1	11.	3.97	6.	41.36	7.85	4.	2.
59.	3.7	2.1	-14	4.57	•	47.91	8.57	2.	5
37.	5.1	2.3	.14	5.30	Si	54.73	9.23	8	8
16.	4.9	2.8	.13	99.9	1.	71.96	.3	17.45	-
94.	7.8	12.88	.13	7.82	4.69	81.70		•	
72.	9.5	1.9	.12	90.6		92.68		3.6	6
51.	4.0	1.6	.12	10.27	5.63	103.30	14-11	7.0	2.
6	1.7	1.8	-12	11.78	7	115.50	15.08	30.74	9
	3.0	2.7	-12	13-41		128.80	16.18	4.8	0
9	5.2	1.2	.12	5.6	S	145.10	17.53	6	5
64.80	9.0		11.	30.00	5.0	6.0	10.00	2	8.
6	Si	4.7	90.	0.0	0	26.00	•	9	0
•	6.5	3.9	.50	0.0	20.00	6.0	0	0	100.00

BEARING FLEXIBILITY 15 MILLION IN.LB. PER RAD.

PRELAG ANGLE -11.11 DEG. AT -4 DEG THIST ECONE ANGLE 4.6 DEG.

THIST VARIATIONS 0. -4. -8. -16 DEG.

TABLE 8-32

GROSS WEIGHT 30,000 LB., 180-KNOT DESIGN BASIC BLADE DATA H4-R HELICOPTER

OZ	J A AR	ż	8 10.9	.57 21.9	13 20.8	.54 19.3	.15 18.3	.97 17.0	.98 15.9	.90 14.9	6.83 14.01	.63 12.9	.26 11.5	.17 10.8	7.6 11	.58 8.9	.25 8.0	.86 7.1	•44 6°2	.89 4.2	.00 30.0	
SEC- TION	7	O.NI	4	1.	.5	.3	1.	6.	4.	.3	6.26	0.	9.	.5	.3	1.	6.	1.	4.	0.0	0	
EDGE- WISE	IYY	Z	9.9	3.2	1.5	9.3	7.8	6.2	8.8	7.6	26.59	5.0	6.6	5.6	3.6	2.5	0.9	9.2	7.5	0.0	0.0	
SEC- TION	×	-	7	.5	4.	.3	.2	7	.3		2.22	7.	.2	.2	1.	0	0	8	1.	0	0	
FLAT- WISE	×	(IN. 4)	•		3.13			9.	9.	.5	2.41	.2	.2	.2	0.	6.	1.		4.	0.	0	
WALL THICK-	ESS	Z	•06	.13	.13	.14	.15	.16	-117	.18	0.193	.20	.22	.23	.25	.26	.28	.31	.33	64.	00.	
E C		(18.	S	0.7	2.3	2.2	2.1	2.2	1.9	2.1	12.17	2.3	2.8	2.8	1.9	3=1	1.8	2.7	1.2	6.5	4.7	
	무	(IN.)	2.6	2.0	1.4	7.0	0.2	9.6	9.1	8.6	18.10	7.5	6.8	6.4	5.7	5.2	4.7	1.	6	0	8	
	AOI	CIN.	32.0	10.4	88.8	67.2	45.6	24.0	02.4	80.8	259.20	37.6	16.0	4.46	72.8	51.2	29.6	08.0	86.4	4.8	3.2	

BEARING FLEXIBILITY 15 MILLION IN.LB. PER RAD.

THIST VARIATIONS O. -4, -8, -16 DEG.

PRECONE ANGLE 4.15 DEG. AT -4 DEG THIST

PRELAG ANGLE -9.95 DEG.

TABLE 8-33

BASIC BLADE DATA
C1 COMPOUND
1-1 PLANFORM, ARTICULATED BLADE
GROSS WEIGHT 12,000 LB., 200-KNOT DESIGN

			A	FLAT-	Ū	90	W	TOR-	MID
		SEGNENT	THICK-	MI SE		WISE	TION	SION	-
RADII	CHORD	EIGH	ES	IXX	×	IY	>	7	2
LIN.	(IN.)	2		(IN.4)	(IN.3)	Z	(IN.3)	(IN.4)	
36.0		.2	.07	0.98	0	0.3	•	0	
19.2	.2	10.99	+1.		8	0.5	) (	0	0
02.4	8.2	8.8	+1.	0	4	7-0		•	0
0	18.25	8.40			1.90	0	5.10		13.00
68-8	8.2	8.27	.15	•	6.	1.0			0
52.0	.2	8.26	-15	2.13	0	3.8		9.	-
38.2	1.2	8.31	91.	2.20	0	4.0		6	13.16
18.4			91.	2.30	7.	4.5		7.	13.20
1.6	1.2	S	111	2.31	.2	4.8		4	~
4.8	8.2	9	-17	2.47	.2	7.0	•	7.65	3
8.0	8.2	6.	.18	2.51		7.2		7.90	3
1.2	.2	0	.18	•	.3	7.8		.2	+
134.40		-	•10	2.68	4.	8.5		5	4.
1.6	8.2		.19			9.0	•	1.	S
0.8	.2	0	-20	2.88	9.	9.5	6.70	0	5
84.00	8.2	.2	.20		9.	0.0	•	9.	0
1.2	8.10	*	.2I	3.10	1	1.2	•	4.0	
4.	-	2.1	.27		2.00	7.8		0.0	14.85
• 6	-	9.1	.50	0	15.00	0.0	10.00	0	
16.80	-	1.8	00.	0.	18.00	5.0	15.00	0.0	0.0
11.63	9.10		90.	75.00	18.00	0.	15.00	•	0

DESIGN THIST -4 DEG.

TABLE 8-34

BASIC BLADE DATA
C1 COMPOUND
N.L. PLANFORM, ARTICULATED BLADE
GROSS WEIGHT 12,000 LB., 200-KNOT DESIGN

		GROSS	WEIGHT 12	000 LB.	200-KNDT	T DESIGN			
			A		U	3	U	T08-	9
		EGME	THICK-	MI SE	TION	WISE		2	LINE
RADII	CHORD	H91	W		××	>	ZYY	<b>ب</b>	ď
ż	( .N.)	(LB.	(IN.)	(IN.4)	(IN.5)	Z	(IN.3)	(IN.4)	Z
36.0	6.08	.2	.16	0.12	0.22	8	8	4	.2
19.2	-	6.	3		94.0	1.	1.	6.	.5
02.4	2.1	8.8	.23		_	7.	.8	.2	• 6
-	_	8.40	.18	1.29	1.42	13.94	3.91	3.98	9.65
68.8	8.2	.2	.15	•	1.92	1.0	.2	.3	0
52.0	8.2	.2	0.155	7.	0	3.8	.5	9.	-
35.2	18.25		116		0	4.0	• 6	6.	-
1.8.4	8.2	4	116	.3	7.	4.5	1	-	.2
9.10	8.2	Si	111	3	.2	4.8	.8	4.	.2
84.8	18.25	6.	117	*	.2	7.0	1.	9.	.3
68.0	8.2	6.	.18		.3	7.2	.2	6.	.3
51.2	8.2	0	.18	.5	.3	7.8	.2	.2	4.
34.4	18.25	9.16	119	•	*	8.5	4.	.5	4.
117.60	18.25	8	.19	1.	2.50	29.00	.5	8.70	13.50
8.00	18.25	8.03	.20	•	9.	9.5	6.70	0	.5
4.0	18.25	.2	.20	6.	9.	0.0	8	9.	9.
7.2	8.10	4.	.20	7.	.7	1.2	7	4.0	
4.0	-	12.19	.27	8.	2.00	7.8	9.	0.0	14.85
.6	1	9.1	.50	ö	15.00	0.0	10.00	5.0	20.00
6.8	8.10	71.84	00.	5.0	18.00	5.0	15.00	0	100.00
12.63	1.	14.80	2.000	•	18.00	5.0	15.00	0.0	100.00

THIST VARIATIONS +4, 0; -4, -8 DEG.

TABLE 8-35

BASIC BLADE DATA
C1 COMPOUND
3-1 PLANFORM, ARTICULATED BLADE
GROSS WEIGHT 12,000 LB., 200-KNOT DESIGN

			AL	ت	SEC-	EDGE-		TOR-	10
		SEGNENT	THICK-	MI SE	-	12	LION	NOIS	
ADI	CHORD	E16H	W	×	×		7	•	RE
CIN.	(IN.)	(18.)	(IN-)	-	-	( IN. )	().NI)	- NI	ż
0.5	2	-2	01.		0.56	1.	9.	4	•
3.2	3.4	10.99	.21		1.12	0.2	•		7.
2.4		8.8	119		3	2.6		.5	1.
	5.8	4	.18		1.50	5.2		4.36	10.55
	-	•	0.170	1.74	1.71	17.98	4.47		2.
~		8.26	116		•	3.6	5.41	94.9	
	6	6	.15		2.19	7.4	5.84	7.80	6.5
60	0	4	.14		4.	2.2	4.		0.6
-	7	S	114		1	7.1	6.	10.92	1.7
•	6	6.	114	6	1.	5.4	6.	6.	4.2
6	•	6	-13	6.	.3	1.0	.5	14.69	6.9
-	5	0	.13	9.	1.	7.6	.2	7	8.6
	26.80		.13	6.53	4.06	65.18	66.6	•	32.89
-	8	8.	.12	Si	4.47	3.1	1	.2	9.0
0	6	0	.12	1.	4.97	6.	1.6	5.4	9.5
	0	.2	.12	6.	5.46	92.90	12.49		2.6
	4	4.	.12	1.4	40.9	105.80	3.7		1.9
0	4.5	2.1	.14	8.5	14.48	8.3	7.3	-	9.1
3	5.0	7	.50	0.0	5.0	0.0	ŏ	5.0	0.0
16.80	5	1.8	2.000	0	18.00		15.00	00.0	0
2	0	8	•00	5.0	8.0	5.0	15.00	0.0	00.0

THIST VARIATIONS +4. 0, -4, -8 DEG.

BASIC BLADE DATA
C1 COMPOUND
1-2 PLANFORM, ARTICULATED BLADE
GROSS WEIGHT 12,000 LB., 200-KNOT DESIGN

			1	FLAT-	SEC-	9	SEC-	TOR	10
RADII	CHORD	WEIGHT		-X	- X	<b></b>		NOTS	LINE
	( .NI )	(18.	Z	-	-	Z	(IN.3)	(IN.4)	. Z
36.0		.2	90.	7	0	3.2	7	7.	
19.		6.	.12	N	7	6.5	*	S	0
2.4	20.10	8.88	0.134	2.50	2.67	25.48	5.40	4	18.08
83.6		8.40	110	•	0	4.1	.2	0	6.9
68.8	6	.2	+1.		6.	2.6	0	1.	5
25.0	8.4	8.26	0.153	2.17	1.97	+	4.	9.	14.77
35.	7.8	.3	.16	2.07		2.7	.2	4.	3.6
19.4	7.3	4	-11	2.02		1.7	.2	1.	2.7
01.6	6.7	Si	-18	•	16-1	0.3	0	.8	1
84.8	7	.9	.20	•	1.86	0.3	-	9.	9.
68.0	2.6	6.	.21	9.	1.80	9.1	0.	.3	9.6
151.20	-	0	.22		1.75	8.0	6.	-	
7.7	9	7.	.24	•	1.69	7.0		6.	
1.6	7		.26		1.64	5.9	9.	.5	.5
0.8	9.	0	-28		1.57	4.7	5	.2	8
4.0	-	-2		7.	1.47	.5	4.29	0	6.13
7.	~		.33	3.1	1.38	2.6		6.	5.44
•	1.	7.	**	*	2.00	.3	7	4.	4.04
3.6	0	9.1	0	0	15.00	0.0	0	5.0	0.0
6.8	0	1.8	2.000	0	18.00	5.0	15.00	0	00.00
12.63	0	4.8	90	2.0	18.00	75.00	15.00	00	

THIST VARIATIONS +4. 0. -4. -8 DEG.

THIST VARIATIONS +4, 0, -4, -8 DEG.

TABLE 8-37

		GROSS	BAS -1 PLANFO WEIGHT 2	SIC BLADE DA C2 COMPOUND ORM, ARTICUL 27,000 LB.,	DATA ND ULATED BL	ADE OT DESIGN			
			=		SEC-	EDGE-	SEC-	TOR-	
		W	THICK-	MISE	-	IS		SION	-
RADII	CHORD	IGHT	ES	×	ZXXZ	177	277	7	4
Z	( .N.)	(18.		CIN.	-	(IN.4)	().NI)	( N N )	(I.N.)
433 00	23.65	4.07	-	1.87	1.38	19.90	3.80	6.	9.55
	3.6	9	16	1	2.92	39.80	7.80	12.70	.2
	3.6	4.5	18	N		42.90	8.50	Ō	4.
367.20	-	15.77	20	•	3.62	53.00	9.80	14.90	19.73
*	3.6	15.74	.21	0	3.80	55.30	10.20		9.8
7	9	17.14	.21	5.42	4.15		11.30	0	0.1
20	3.6	10.29	.22	5.58	4.20	65.30	11.45	0	0.1
16	3.6	17.63	0.224	5.68	4.28	99.00	11.60	19.30	20.20
	9	17.02	.22	5.80	4.35		11.70	9.7	0.5
7	9		.23	5.95	4.40	67.30	11.90	0.0	0.5
9	•	-	.23	90.9	4.48	8.0	12.00	6	4
94.	3	19.91	.24		4.55	8	7.	0.7	M - 0
	3.6	16.42	.24	•	4.60	9.3	12.30	1.0	0
	3.6	•	.24	6.40	4.70	7.	4.	1.4	0
129.60	3.6		.25	4.	4.90	2.	8	1.8	0.5
	1.6	1	.29	7.	•	80.80	.3	4.	1.
3	-	38.11	.37	4.1		124.00	•	. 8	
	-		00	0.00	5.0	00.00	0	0000	000
M	9.71	77.12	0	100.00	25.00	0000		0	0.0
*		4.	3.000	00		100.00		150.00	100.00

DESIGN THIST -8 DEG.

TABLE 8-38

BASIC BLADE DATA
C2 COMPOUND
N.L. PLANFORM, ARTICULATED BLADE
GROSS WEIGHT 27,000 LB., 200-KNOT DESIGN

			WALL	FLAT-	EC	90	n E	TOR-	OI
		GME	THICK-	WISE	TION	S	-		-
RADII	CHORD	EIGH	ESS	IXX	×	Y	77		RF
(IN.)	(IN.)	(18.)	-	(IN.4)	(IN.3)	(IN.4)	(IN.3)	(IN.4)	(IN.2)
32.0		0	.18	.2	6	8	S	-	7
410.40	1.8	0	0.361	0.55	0.78	1.66	3.19	2.20	4.27
88.8	5.7	14.51	.28	.5	9.	7.1	6	3	6
67.2	1.6	5.7	-24	0	.5	5.2	.2	9.0	4.9
45.6	3.6	5.7	.21	0	8	5.3	0.2	6.5	9.8
24.0	9.	7.1	.21	4.	7.	64.80	.3	0	-
02.4	3.6	0.2	.22	.5	.2	5.3	1.4	9.0	0.1
80-8	3.6	1.6	-22	9.	.2	6.0	1.6	9.3	0.2
59.2	3.6	7.0	.22		.3	6.8	1.7	9.7	0.2
37.6	9.6	8.0	.23	6.	4.	7.3	1.9	0.0	0.2
16.0	3.6	7.7	-23	0	4.	8.0	2.0	0.3	0.3
94.4	3.6	9.9	.24	7	Si	8.8	2.1	0.7	0.3
72.8	3.6	4	.24	.2	9	9.3	2.3	1.0	4.0
51.2	3.6	4.9	.24	04.9	1	0.1	2.4	1.4	4.0
29.6	3.6	7.3	.25	4.	6.	2.0	2.8	1.8	0.5
08.0		18.46	.29	8.10		0.8	4.3	3.4	1.0
6.4	1	8.1	.37	4.1	3.2	24.0	2.2	8.8	4.6
4.8	-	9.	90.	0	0	0000	5.0	0.0	0000
m		7.1	00.	0.0	5.0	0.0	5.0	50.0	0000
0	.1	4.5	00.	00.00	5.0	0000	5.0	0.0	0.0

THIST VARIATIONS +4, 0, -4, -8 DEG.

-8 DEG. THIST VARIATIONS +4, 0, -4,

49.93 56.39 61.65 66.44 72.42 100.00 100.00

			IABLE 8-3	39			
	GROSS	BA -1 PLANF WEIGHT	SIC BLADE C2 COMPOU ORM, ARTIC 27,000 LB.	DATA IND ULATED BL	LADE DT DESIGN		
		WALL		u	EDGE-	SEC-	TOR-
	SEGMENT	THICK-	IS	TION	WISE	TION	SION
HOR	EIGH	W	×	××	>	277	7
CIN.		Z	-	(IN.3)		(IN.3)	(IN.4)
15.80	6.	11.	0.89	•	0.1	2.82	6
7	9	.22	-	1.72	0.2	9	•
8	.5	.23	4	-	26.48		3
0	-1	.23	•	2.73	8.5	8.66	9
2.	15.74	.22	4.24	3.21	7.1	6	*
3.	-	.21	5.45	•	5.1	2.4	
5	.2	0.204	6.62	4.35	76.43	13.63	
.9		.19	9.	4.76	6.8		5.8
8	0	.19	.3	0	2.9	5.3	7.9
0		.18	10.40	5.78	0.	0	4.1
-		7.	11.90	.2	-	8.	•
3.	.6	•16	13.65	. 8	43.9	9.6	44.39
+	*	•10	14.84	7.20	155.30	20,58	48.29
6.	4.	.15	17.31	7.93	77.7	2.2	56.03
1.	.3	•15		8.44	00.2	3.8	2.4
•	4.	.16	26.92	1.3	46.5	8.2	7.4
•	38.11	•19	17.7		86.3	4.8	4.46
.9	9.	00.	100.00	5.0	0.00	5.0	000
6.	77.12	0	0.0	25.00	0.0	5	0
	4.5	.00	000	5.0	000	5.0	50.

5.80 11.61 14.06 16.35 19.10 22.37 26.07 29.29 31.00 37.43 41.84

AREA (IN.2)

MIO-

345.66 324.06 302.46 280.86 259.26 237.60 172.80 172.80 151.20 159.60

TABLE 8-40

BASIC BLADE DATA
C2 COMPOUND
1-2 PLANFORM, ARTICULATED BLADE
GROSS WEIGHT 27,000 LB., 200-KNOT DESIGN

			WALL	FLAT-	SEC-	EDGE-			-01W
		SEGMENT	THICK-	WI SE	LION	WISE			LINE
RADII	CHORD	WEIGHT	NESS	, XXI	XXZ	IYY			AREA
(IN.)	( .NI )	(18.)	( IN.)	(IN.4)	( IN. (2)	(1N.4)	( IN. C)	(IN.4)	(IN.Z)
•		•	0.072	2.40	1.51	25.14	4.59	7.48	14.68
	•	6	0.144	4.80	3.03	50.29	61.6	14.97	29.36
	5	4	0.168	80.5	3.29	51.26	9.65	16.43	27.54
	5	3	0.192	5.41	3.61	59.81	10.98	18.21	25.57
	;	5	0.205	5.44	3.71	59.22	11.22	18.23	24.11
	3.	7	0.217	5.39	3.81	64.50	12.38	18.91	22.16
•	2.	0	0.228	5.16	3.75	60.17	12.04	17.74	20.63
	2.	~	0.239	4.91	3.67	57.84	11.79	17.03	19.34
259.20	21.60	17.02	0.252	4.62	3.57	54.45	11.48	16.13	17.95
	-	8	0.265	4.40	3.50	51.39	11.15	15.24	16.76
	•	1.	0.281	4.09	3.36	47.98	10.81	14.40	15.43
	6	9	0.297	3.79	3.22	44.63	10.42	13.40	14.11
	•	16.42	0.316	3.46	3.05	41.18	00.01	12.42	12.88
	•	9	0.336	3.16	2.89	37.89	9.58	11.54	11.64
	•	-	0.365	2.80	5.66	35.11	9.18	10.53	10.42
•	•		0.434	2.97	2.93	35.09	9.55	10.59	90.37
•	•	8	0.710	3.50	•	28.04	8.69	23.93	44.19
•	•	;	3.000	100.00	25.00	100.00	25.00	100.00	100.00
•	•	~	3.000	100.00	25.00	100.00	25.00	150.00	100.00
24.00	•	84.59	3.000	100.00	25.00	100.00	25.00	150.00	100.00

THIST VARIATIONS +4, 0, -4, -8 DEG.

DESIGN THIST -2 DEG.

TABLE 8-41

		GROSS	BAS -1 PLANFO WEIGHT 1	C3 COMPOURS, AN, ARTIC	DATA UND CULATED BL	ADE T DESIGN				
ADII IN. J	CHORD	SEGMENT WEIGHT (LB.)	WALL THICK- NESS (IN.)	FLAT- WISE IXX (IN.4)	SEC- TION ZXX (IN.3)	EDGE- NISE IYY (IN.4)	SEC- TION ZYY (IN. 3)	TOR- SION J. 4)	MID- LINE AREA (IN.2)	
90	18.25	2.27	0.072	•	_	00	N. C		12.94	
2.4	5	8.8	*1	0		;;		6.02	12.98	
68.80	18.25	8.27	0.151	2.02	1.90	20.90	5.20	6.15	13.00	
2.0	•	.2	.15	-	0	3	5	•	13.12	
35.20	18.25	8.31		7 "			-	6.90	13.16	
1.6	.2	.0	117		2.20	*	. 8	7.40	13.25	
4.8	.2	6.	.17	4.	•	7.	7.	•	.3	
51.20	18.25	8.97	.18	2.51	•		2.0	7.90	13.38	
4.4	.2	-	.19	9		8				
7.6	8.2		•19	•	•	6	S	•	.5	
0.8		0	.20	•	9.	6		•	.5	
4.0		.2	.20	6.	2.65	0	6.80	09.6		
	8.10	4.	.21	-		1.	•	+	-	
0.4	~	2.1	.2	•		7.	•	20.00	14.85	
3.6	8.10	69.17	Ŏ		15.00	70.00	10.00	5.0	50.00	
9	7.	1.	0		18.00	75.00	15.00	0.0	100.00	
12.63	8.10	4-8	90		18.00	15.00	15.00	000	00	

TABLE 8-42

BASIC BLADE DATA
C3 COMPOUND
N.L. PLANFORM, ARTICULATED BLADE
GROSS WEIGHT 14,000 LB., 250-KNOT DESIGN

2		0		.2	5	9	9.	0	-	7	7	.2	3	3	13.40	4.	5	5	9.		8	0	0.0	
9	SION	7	(1N.4)	4	6	.2	6.		9.	6.	-	4.	9.	6.	8.25	5	1	0	9.	4.0	0.0	0	0.0	
u	TION			8	1	8	6.	.2	.5	9.	1.		7.	.2	6.20	4.	.5	1		7.	9.	0	0	(
2	WISE WISE	IYY		8	1.	-	3.9	1.0	3.8	4.0	4.5	4.8	7.0	7.2	27.80	8.5	9.0	9.5	0.0	1.2	7.8	0.0	5.0	-
u	110N	×	H	.2	4.	6.	4.	6.	0.	0	7	.2	7		2.36	4.	5	9.	9.		0		0	(
	MISE	×	(IN.4)			69.0		2.06	2.13	•	2.30	2.38	2.47	2.51	2.59				2.97	3.10	6.80		75.00	
-	THICK-	NESS	2	.16	.33	.23	-18	.15	-15	91.	-16	-17	-17	118	0.185	119	•19	.20	.20	.20	.27	.50	.00	
	EGME	WEIGHT	(18.)	.2	10.99	8.88	8.40			8.31		8.53	8.96	8.97	9.04	7	7.85		8.22	*	2.1	7.	1.8	74 00
		CHORD	(IN.)	0	7	12.16	7	7				.7			18.25	8.2		18.25	18.25	8-10	8.10	7	8.10	
		RADII	(IN.)	36	319.20	02.4	85.	68.8	52.	236.20	218.40	9. D	184.80	200	51.2	36.4	-	8.0	4.0	8.2	4.0	33.60	6.9	13 43

THIST VARIATIONS +2, 0, -2, -4 DEG.

BASIC BLADE DATA

C3 COMPOUND

3-1 PLANFORM, ARTICULATED BLADE S WEIGHT 14,000 LB., 250-KNOT DESIGN

GROSS WEIGHT 14,000 LB

26.99 16.56 19.05 21.70 50.00 7.18 8.79 10.55 12.45 14.41 24.23 32.89 36.03 39.28 42.66 46.19 40.14 00.00 AREA IN 2 LINE 5 MID-IN. 4) 1.41 2.83 3.59 4.36 5.32 6.46 10.92 12.98 14.69 17.15 19.66 22.25 25.40 29.33 35.34 65.76 100.00 SION IN.3) •63 3.69 4.10 6.99 10.77 11.68 12.49 13.72 17.37 5.84 8.52 TION .26 9.99 ZYY 4.47 5.41 (IN.4) 65.18 73.16 82.90 92.90 5.13 10.25 12.61 17.98 27.42 32.21 37.17 45.41 51.04 138.30 EDGE-105.80 WISE IYY 2XX (1N.3) SEC-TION 14.48 15.00 18.00 4.47 6.04 5.46 FLAT-WISE IXX (IN.4) 11.46 28.51 0.45 4.94 5.68 6.53 7.51 8.71 50.00 1.1.2 2.1.4.2 2.1.2 3.0.5 4.34 4.34 WALL THICK-NESS (IN.) 120 120 120 120 120 120 120 120 120 00000000000000000 10.27 10.99 10 SEGMENT WEIGHT (18.) 12.00 10.00 10.00 10.00 10.00 10.00 10.00 10.00 10.00 10.00 10.00 10.00 (IN.) CHORD 336.00 319.20 285.60 268.80 252.00 235.20 235.20 218.40 168.00 1117.60 100.80 100.80 1117.60 (IN.)

DEG. 5--2, 0 +2. THIST VARIATIONS

BASIC BLADE DATA
C3 COMPOUND
1-2 PLANFORM, ARTICULATED BLADE
GROSS WEIGHT 14,000 LB., 250-KNOT DESIGN

MID- LINE AREA (IN.2)	60	18.08	20		3.6	5-	9.0	9.6	0		S	8	6.13	5.44		0.0	0.0	0
TOR- SION J. 4)	7.5	7.43	0 ~	.6	*	- 4	9	6	7	6.	S	4.26	0	0	4.	5.0	0000	0
SEC- TION 2YY (IN.3)	-	2.40	70	*	7	70	7	0	6.		9.	.5	•	7.	.2	0	0	15.00
EDGE- NISE IVY (IN.4)	13.29	4	22.65	+		1.7	0	9.1	9.0	7.0	5.9	4.7	3.5	2.6	2.3	0.0	5.0	5.0
SEC- TION ZXX (IN.3)	0-	2.07	50	•	0.0		8	0	.7	9.	9.	5	*		0	15.00	0	18.00
FLAT- WISE IXX (IN.4)	1.29	N	2.24		2.07		1.80	1.68	1.58	1.49	1.38	1.28	1.16	1.04	4	0	75.00	0
WALL THICK- NESS (IN.)	0.064	.13	241.0	-15	-16		.20	.21	.22	.2	•	.2	.30	.33	*	.50	90.	2.000
SEGNENT WEIGHT (LB.)	2.27	8.8	8.27	8.26	6	8.53	96-8	8.97	•	91.6	0	0		*	2.1	69.17	71.84	14.80
CHORD LIN. 1	20.60	•	18.90	•	17.80			15.60	16.10	•	•	13.60	•	•	•	•	•	2.00
EADII CAN.	334.00			•	238-20	262.65	•	168.00	•	•	3.6	9			4.0	3.6		12.63

THIST VARIATIONS +2. 0. -2. -4 DEG.

TABLE 8-45

1-1 PLANFORM, ARTICULATED BLADE

C4 COMPOUND

BASIC BLADE DATA

45.20 43.20 44.20 44.70 45.70 50.50 100.00 150.00 43.00 43.40 43.70 43.10 43.30 45.80 43.00 AREA (IN.2) LINE 120.00 (IN.4) 78.00 50.30 52.30 53.50 300.00 300.00 59.00 62.50 70.00 87.00 95.00 56.00 57.30 58.00 SION 54.80 2YY (18.3) 24.30 25.00 25.30 26.00 29.00 34.00 36.80 39.30 100.00 150.00 24.00 31.80 26.30 27.00 27.50 SEC-TION 23.00 GROSS WEIGHT 30,600 LB., 250-KNOT DESIGN (IN.4) 208.00 180.00 188.00 314.00 398.00 432.00 500.00 225.00 248.00 270.00 291.00 205.00 195.00 200.00 EDGE-IYY (IN.3) 12.80 14.10 9.50 9.80 10.00 10.20 10.50 10.80 11.50 10.40 16.80 30.50 15.50 SEC-TION 4.50 9.00 9.10 9.40 XX7 (IN.4) FLAT-NISE 84.00 22.00 28.30 31.70 20.20 8.50 17.00 18.30 19.30 20.00 34.60 150.00 19.00 18.60 18.00 IXX WALL THICK-.000 .500 000 (IN.) 0.260 0.303 0.362 .000 0.233 0.250 0.223 0.390 NESS 0.215 0.107 SEGMENT 28.35 31.08 29.73 26.72 27.53 59.00 35.96 113.75 23.73 23.52 25.77 26.04 26.63 26.04 24.78 24.78 40-14 **WEIGHT** 118.1 36.00 36.00 36.00 36.00 36.00 36.00 CIN-CHORD 226.00 226.00 2273.00 2273.00 2273.00 2273.00 2273.00 2273.00 2273.00 2273.00

DESIGN THIST -2 DEG.

-2, -4 DEG.

0

THIST VARIATIONS +2.

BASIC BLADE DATA
C4 COMPOUND
N.L. PLANFORM, ARTICULATED BLADE
GROSS WEIGHT 30,000 LB., 250-KNOT DESIGN

NID- LINE AREA (IN. 2)	00.	36.28	3.0	30.	43.40	5.2	5.7	000
10R- S10N J4	9.1	34.81	4.0	8.0	2.5	5.0	20.0	000
SEC- TION ZYY (IN. 3)	+00		500	9:0	PO-		8 9	000
EDGE- WISE IYY (IN.)		24.2	93.0	0.80		91.0	14.0	32.0
SEC- TION ZXX (IN. 3)	1.27	U 4 N	8-60	140	010	4.1	6.8	20.00
FLAT- WISE IXX (IN.4)	66	11.69	8-3	0.00	700	8-3	4.0	000
WALL THICK- NESS (IN.)	• •	0.230	• •		• •	• • •	• •	3.000
SEGMENT WEIGHT (LB.)			+10	0.00		10.0	60	113.75
CHORD (-IN.)	• •	30.00			36.00		• •	
24011 168.	200		98		270-00	• • •		<b>63.</b> 00

TABLE 8-47

SASIC BLADE DATA
C4 COMPOUND
3-1 PLANFORM, ARTICULATED BLADE
GROSS WEIGHT 30,000 LB., 250-KNOT DESIGN

NID- LINE AREA (IN.2)	3.1	6.5	0.3	9.3	99.2 19.8	131.00 142.70 154.90	63.6	50.0
TOR- SION J. 4)	800	5.00	63	97.1	33.8 68.9	207.90 252.30 300.90	33.3	0000
SEC- TION 2YY (IN.3)	7.5	9.7	6.2	3.8	1.2	55.06 62.61 70.13	95.1	0.0
EDGE- NISE IYY (IN. 4)	45.0 90.0	37.2	24.8	62.8	69.1 60.2 58.6	670.00 795.50 933.10	61.0	900
SEC- TION ZXX (IN. F)	0-0		9.4	1.2	5.3	22.07 26.25 30.81	5.7	0.0
FLAT- WISE IXX (IN.4)	4.1	0 6 4	1.7	9.2	6.4 9.0		1.2	150.00
WALL THICK- NESS (IN.)	0.150	25 25	22.	20-	0.190	0.210 0.220 6.230	.00	3.000
SEGMENT WEIGHT	40.14	23.73	25.77	9.9	4.5	29.73 31.08	9.0	137.50
CHORD CIN.)	26.40			MIGO	600	\$5.20 \$7.60 60.00	3 3	
RADII CEN. J	399.00		296.00	• •	9 0	126.00	+ 6	<b>42.</b> 00

THIST VARIATIONS +2, 0, -2, -4 DEG.

TABLE 8-48

BASIC BLADE DATA C4 COMPOUND 1-2 PLANFORM, ARTICULATED BLADE GROSS WEIGHT 30,000 LB., 250-KNOT DESIGN

				FLAT-		EDGE-	SEC-		-01W
		SEGMENT		MISE		WISE			LINE
RADII	CHORD	WE I GHT		IXX		IYY			AREA
	CIN.)	(18.)	( NI)	(IN.4)	( IN. C)	(IN.4)		(IN.4)	IN.Z.
		,				:			,
	00.14	20.0	0000	10.13	24.4	01-11	84.71	21.50	08.31
	40-10	<b>*1-0</b> *	0.192	21.58	8.97	222.20	24.96	63.00	68.31
	39.10	23.52	0.202	20.79	8.86	214.40	24.57	60.31	64.65
	38.10	23.73	0.210	20.20	8.84	207.50	24.56	58.76	61.12
	37.10	24.78	0.223	19.26	8.65	200.40	24.20	56.03	57.68
•	36.10	24.78	0.232	18.41	8.50	194.10	24.50	54.83	54.24
•	34.90	25.77	0.248	17.52	8.37	183.40	23.61	51.40	50.35
•	33.90	26.04	0.259	16.56	8.14	175.80	23.43	49.97	47.15
	32.90	26.04	0.274	15.84	8.02	168.80	23.22	47.16	44.04
	31.90	26.63	0.288	15.02	7.85	160.10	22.68	44.17	41.08
	30.90	26.72	0.306	14.11	1.61	152.00	22.29	42.71	38.12
	29.10	28.35	0.339	13.88	1.19	148.00	22.62	42.15	34.52
	28.70	27.53	166.0	14.37	8.34	149.50	23.68	44.05	31.39
	27.60	29.13	9*4*0	14.26	8.61	147.60	24.46	04.44	28.10
•	26.60	31.08	0.510	14.16	8.88	144.90	24.94	44.33	25.16
•	25.60	35.96	0.581	13.68	8.91	139.70	24.91	43.28	22.31
	10.60	29.00	0.828	19.52	13.22	136.40	24.80	62.85	15.50
•	10.60	113.75	2.000	130.00	50.00	432.00	100.00	300.00	100.00
	10.60	137.50	3.000	150.00	50.00	500.00	150.00	300.00	150.00
30.00	10.60	52.50	3.000	150.00	50.00	500.00	150.00	300.00	150.00

THIST VARIATIONS +2, 0, -2, -4 DEG.

AT O DEG DESIGN TWIST

DEG.

2.45

PRECONE ANGLE

PRELAG ANGLE -4.12 DEG

TABLE 8-49

			BASI	BLADE	ATA				
		GROSS		FORM, RI	GID BLADE	T DESIGN			
			AL	_	SEC-	EDGE-			01
		EGME	THICK-	WISE		WISE	LION	SION	LINE
	HOR	GHT	ESS	×	ZXX Z	177	2777		AREA
_	(IN.)	(LB.	( IN )	(IN.4)	-	CIN.	O.N.	( NI )	Z
0	8.2	~	.07	0.98		0.3	3	2.90	12.94
20	8.2	0	14	6	1.84	3.5	•	5.90	12.94
9	18.25	8.8	1.		1.88	20.70	5.10	0	12.98
909	8.2	4	.15	0	1.90	0.9	•		13.00
80	8.2	7	15	0	1.92	1.0	.2	6.30	13.00
00	8.2	7	.15	1.	0.	3.8	.5	9.	13.12
20	8.2	3	.16	.2	0	4.0	• 6	6.	13.16
04	8.2	4	116		7.	4.5	. 7	7.	13.20
09	8.2	N	.17	6	.2	4.8	8	4.	.2
80	8.2	6	.17	4.	.2	7.0	7.	9.	13.35
00	8.2	6	.18	.5	.3	7.2	.2	6.	.3
20	8.2	0	.18	S	6.	7.8	.2	-2	4.
40	8.2	7	119	9.	4.	8.5	4.	.5	4.
90	8.2	8	.19	-	.5	9.0	6.50	8.70	13.50
80	8.2	0	.20	8	2.60	9.5		0	13.55
00	8.2	2	.20	6.	•	0.0	8	09.6	13.60
20	8.1	4	.21	1.	1	1.2	7.10	4.0	
40	-	2.1	.27	0.	0.	3.0	0	0.0	8.4
09	-	9.1	.50	•	0	3.	0	35.00	50.0
80	1	1.8	.00	0	0.	3.0	00-9	0.0	0.0
63	8.10	14.80	2.000	2.00	3.00	23.00	00-9	00.0	000

BEARING FLEXIBILITY 9 MILLIGN IN.LB. PER RAD.

336. 319. 285. 285. 252. 235. 218. 201. 100. 100. 100.

TABLE 8-50

BASIC BLADE DATA

C1-R COMPOUND

N.L. PLANFORM, RIGID BLADE
GROSS WEIGHT 12,000 LB., 200-KNOT DESIGN

|        |       |        | AL     | LA   | EC   | 90    | EC     | OR     |        |
|--------|-------|--------|--------|------|------|-------|--------|--------|--------|
|        |       | EGME   | THICK- | WISE | TION | S     | -      | SION   | Z      |
| RADII  | HOR   | WEIGHT | ESS    | ×    | ×    | IYY   | 77     | 7      | 2      |
| -NI    | (IN.) | (18.   | Z      | -    | -    | -     | (IN.3) | (IN.4) | (IN.2) |
| 36.0   | 0     | .2     | .16    |      | 2    | 00    | α      | 4      | 2      |
| 19.2   | -     | 6.     | .33    | .2   | 4.   | 1     | -      | 6      | 5      |
| 02.4   | 2.1   | 8.8    | .23    | 9.   | 6.   | 7     | 8      | .2     | 9      |
| 285.60 | 15.20 | 8.40   | 0.184  | 1.29 | 1.42 | 13.94 | 3.91   | 3.98   | 9.65   |
| 68.8   | 8.2   | .2     | .15    | 0    | 6.   | 0.    | .2     | .3     | 3.0    |
| 52.0   | 8.2   | .2     | .15    | 7.   | 0    | 3.8   | .5     | • 6    | -      |
| 35.2   | 8.2   | .3     | .16    | .2   | 0.   | 4.0   | 9.     | 6.     | 3.1    |
| 11.4   | 8.2   | 4.     | .16    | 6    | 7.   | 4.5   | 1.     | 7.     | 3.2    |
| 01.6   | 8.2   | .5     | .17    | .3   | .2   | 4.8   | 8      | 4.     | 3.2    |
| 84.8   | 8.2   | 6.     | .17    | 4.   | .2   | 7.0   | 1.     | 9.     | 3.3    |
| 68.0   | 8.2   | 6.     | .18    | ·S.  | .3   | 7.2   | .2     | 6.     | 3.3    |
| 51.2   | 8.2   | 0.     | .18    | .5   | .3   | 7.8   | .2     | .2     | 3.4    |
| 34.4   | 8.2   | 7.     | •10    | 9.   | 4.   | 8.5   | 4.     | .5     | 3.4    |
| 17.6   | 8.2   | 8      | •19    | -    | .5   | 9.0   | .5     | .7     | 3.5    |
| 00.8   | 8.2   | 0      | .20    | 8    | 9.   | 9.5   | .7     | 0      | 3.5    |
| 4.0    | 8.2   | .2     | .20    | 6.   | • 6  | 0.0   | 8      | .6     | 3.6    |
| 7.2    | -     | 4.     | • 20   | .1   | .7   | 1.2   |        | 4.0    | 3.7    |
| 4.0    | -     | 2.1    | .27    | 0    | 0.   | 3.0   | 0.     | 0.0    | 4.8    |
| 3.6    | 7.    | 7.     | .50    | 0    | 0.   | 3.0   | 0      | 0.     | 0.0    |
| 6.8    | -     | 1.8    | 00.    | 0    | 0.   | 3.0   | 0      | 00.00  | 0.00   |
| 2.6    | -     | 4.8    | 00.    | Ō    | 0    | 3.0   | 0      | 00.00  | 0.0    |

BEARING FLEXIBILITY 9 MILLION IN.LB. PER RAD.

PRELAG ANGLE -3.3 DEG. PRECONE ANGLE 2.45 DEG. AT 0 DEG TWIST

THIST VARIATIONS +4. 0, -4, -8 DEG.

TABLE 8-51

BASIC BLADE DATA
C1-R COMPOUND
3-1 PLANFORM, RIGIE BLADE
GROSS WEIGHT 12,000 LB., 200-KNOT DESIGN

| MID-<br>LINE<br>AREA<br>(IN.2)  | 3.59<br>10.55<br>10.55<br>10.05<br>10.05<br>100.00  | •      |
|---------------------------------|---|--------|
| TOR-<br>SION<br>J               | 12.83<br>65.35<br>17.15<br>17.15<br>19.00<br>100.00   | 0      |
| SEC-<br>TION<br>ZYY<br>(IN.3)   | 3.26<br>3.26<br>4.10<br>6.47<br>6.99<br>6.99<br>10.00<br>10.00<br>10.00   | )<br>) |
| EDGE-<br>WISE<br>IYY<br>(IN.4)  | 5.13<br>10.25<br>12.61<br>17.21<br>17.98<br>23.66<br>27.42<br>37.17<br>45.41<br>65.18<br>65.18<br>18.00<br>18.00  | ٠<br>۵ |
| SEC-<br>TION<br>ZXX<br>(IN.4)   | 10.56<br>1.12<br>1.12<br>1.13<br>1.13<br>1.13<br>1.13<br>1.13<br>1.13   | 2.0    |
| FLAT-<br>WISE<br>IXX<br>(IN.4)  | 0.00<br>0.45<br>11.15<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95<br>0.95 | 0.0    |
| WALL<br>THICK-<br>NESS<br>(IN.) | 0.100<br>0.210<br>0.190<br>0.180<br>0.170<br>0.150<br>0.140<br>0.120<br>0.120<br>0.120<br>0.120<br>0.120<br>0.120   | • 00   |
| SEGMENT<br>WEIGHT<br>(LB.)      | 10.99<br>10.99<br>8.89<br>8.27<br>8.26<br>9.96<br>9.96<br>9.04<br>12.19<br>69.17  | 4.8    |
| CHORD (IN.)                     | 12.20<br>13.40<br>14.60<br>15.00<br>16.50<br>16.50  | 5.0    |
| RADII                           | 336.00<br>319.20<br>302.40<br>285.60<br>252.00<br>252.00<br>235.20<br>235.20<br>184.80<br>151.20<br>151.20<br>117.60<br>117.60<br>117.60<br>117.60  | 2.6    |

# BEARING FLEXIBILITY 10 MILLION IN. LB. PER RAD.

### PRELAG ANGLE -3.62 DEG. PRECONE ANGLE 2.47 DEG. AT 0 DEG TWIST

TABLE 8-52

BASIC BLADE DATA

CI-R COMPOUND

1-2 PLANFORM, RIGID BLADE
GROSS WEIGHT 12,000 LB., 200-KNOT DESIGN

|        |       |        | AL     | ~      | ш       | 90      | S<br>C |        | -      |
|--------|-------|--------|--------|--------|---------|---------|--------|--------|--------|
|        |       | GME    | THICK- | WI SE  | 10      | S       |        |        | Z      |
| RADII  | 9     | E I GH | ESS    | IXX    | ×       | 7       | 7      | ,      | 3 0    |
| N.     | -     | (18.)  | Z      | (IN.4) | (IN. W) | (IN. 4) | Z      | (IN.4) | (IN-R) |
| 36.0   | 1.0   | .2     | •06    | .2     | •       | 3.2     | 7      | -      | ď      |
| 19.2   | 9.0   | 6.     | .12    | 5      |         | 6.5     | 7      | . (C   |        |
| 02.4   | 0.1   | 8.8    | .13    | S      |         | 2       | 7      | , 1    | ) C    |
| 85.6   | 9.5   | 4.     | .14    | 3      |         | 4.1     |        |        | 9 0    |
| 68.8   | 8.9   | .2     | +1.    | 7      | 1.97    | 2.6     | 10     |        | 5      |
| 52.0   | 8.4   | .2     | .15    | 7.     | 6       | 4.2     | 4      | . 9    | 4.7    |
| 235.20 | 17.80 | 8.31   | 0.164  | 2.07   | -       | 22.72   | 5.28   | 4      | ٠ ٧    |
| 18.4   | 7.3   | 4.     | .17    | 0      | 9       | 1.7     | -2     |        | 7.0    |
| 01.6   | 6.7   | .5     | .18    | 6.     | 6.      | 0.3     | 0      | 8      | 1.7    |
| 84.8   | 1.9   | 6.     | .20    | 8      | 8       | 0.3     | 7      | 9      | 0.6    |
| 68.0   | 5.6   | 6.     | .21    | 9.     | 8       | 9.1     | 0      | 3      | 9.8    |
| 51.2   | 5.1   | 0.     | .22    | S      | 1       | 8.0     | 6.     | 7      | 0      |
| 34.4   | 4.6   | 1.     | .24    | 4.     | .6      | 7.0     | .8     | 6      | 6      |
| 17.6   | 4.1   | .8     | .26    | .3     | • 6     | 5.9     | 9.     | 5      | S      |
| 8.00   | 3.6   | 0      | .28    | .2     | .5      | 4.7     | .5     | .2     | 8      |
| 4.0    | 3.1   | .2     | .30    | -      | 4.      | 3.5     | .2     | 0      |        |
| 7.2    | 1.    | 4.     | .33    | 0      |         | 2.6     | 7      | 0      | 1      |
| 9.4    | 4.    | 2.1    | .46    | 4.     | 0       | 0.0     | 0      | 4      | C      |
| 3.6    | 0     | 1.     | .50    | 0      | 0       | 0.0     | 0      | 5.0    | 0.0    |
| 6.8    | 0     | 1.8    | 00.    | 0      | 0       | 0.0     | 0      | 00.00  | 0000   |
| 5.6    | 0     | 4.8    | 00.    | 0      | 0       | 0.0     | 0.     |        | 100.00 |

BEARING FLEXIBILITY 12 MILLION IN.LB. PER RAD.

PRELAG ANGLE -4.37 DEG. PRECONE ANGLE 2.38 DEG. AT 0 DEG TWIST

THIST VARIATIONS +4, 0, -4, -8 DEG.

CONE ANGLE

PRE

TABLE 8-53

| 10.00 100.00 | 0 150.0                               |
|--------------|---------------------------------------|
| 00           |                                       |
|              | 0                                     |
| 43.00        | 90                                    |
| 7.00         |                                       |
| 10.00        | 10.00                                 |
| 3.000        | 00                                    |
| 124.62       | 4.5                                   |
| 9.71         |                                       |
| 64.80        | 4.0                                   |
|              | .80 9.71 124.62 3.000 10.00 7.00 43.0 |

20.12 20.15

19.73

9.55 19.20 19.40

AREA (IN.2)

LINE

FLEXIBILITY 20 MILLION IN.LB. PER RAD. BEARING

20.20 20.23 20.28 20.36 20.36 20.40 20.57 21.00 100.00 100.00

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TABLE

20.15 20.23 20.57 2.13 8.98 20.12 14.90 20.20 20.30 20.28 20.36 20.40 20.43 21.00 24.60 19.86 100.00 AREA (IN.2) LINE (IN. 4) 20.75 21.05 21.40 21.85 1.10 18.00 19.30 19.70 5.34 SION TOR-20.30 23.40 48.80 10.60 16.55 20.00 (IN.3) 11.45 1.59 12.00 12.10 12.30 TION YY2 5.30 8.24 12.40 0.20 11.30 11.70 11.90 12.80 14.30 22.20 10.00 WEIGHT 27,000 LB., 200-KNOT DESIGN (IN.4) 99.99 68.00 99. 3.00 55.30 64.80 65.30 66.80 67.30 68.80 70.10 72.00 43.00 17.13 35.24 69.30 80.80 24.00 EDGE-WISE IYY PLANFORM, RIGID BLADE E.NI) SEC-TION 0.78 1.60 2.56 4.15 4.40 4.48 4.60 4.90 5.80 00.9 7.00 4.28 4.35 4.55 4.70 7.00 BASIC BLADE DATA C2-R COMPOUND 4.N1) FLAT-WI SE 5.68 5.95 5.80 5.80 5.80 0.55 6.05 6.18 6.40 6.45 0.00 6.25 8.10 0.00 1.51 0.00 IXX THICK-(IN.) NESS 1.249 0.221 .228 0.237 .180 .216 .249 .000 WALL .361 .287 .212 .232 .375 000. 0.290 N.L. 0.258 0 GROSS SEGMENT 9.60 15.74 0.29 17.63 18.04 16.42 17.33 24.62 77.12 84.59 6.97 17.71 4.51 18.46 WEIGHT (18.) 16.42 38.11 16.61 11.82 15.76 19.70 23.65 23.65 23.65 23.65 23.65 23.65 23.65 23.65 23.65 CHORD 9.71 9.71 9.71 .71 388.80 410.40 302.40 280.80 194.40 151.20 108.00 86.40 432.00 367.20 345.60 324.00 259.50 237.60 216.00 172.80 129.60 64.80 43.20 24.00

FLEXIBILITY 20 MILLION IN.LB. PER RAD. BEARING

DEG. 8--4. THIST VARIATIONS +4. 0.

-3.35 DEG.

PRELAG ANGLE

O DEG TWIST

AI

3.38 DEG.

PRECONE ANGLE

(IN.) RADII

TABLE 8-55

C2-R COMPOUND
3-1 PLANFORM, RIGIO BLADE
GROSS WEIGHT 27,000 LB., 200-KNOT DESIGN

| MID  | -    | 0      | (IN.2)  | α    | \ -    | 14.06 | 6.3  | 9.1  | 2.3  | 0.9  | 9.2  | 1.0  | 7.4  | 1.8  | 9.9  | 9.6  | 6.3   | 1.6  | 6.4  | 2.4  | 0000 | 0.0  | 0000 |
|------|------|--------|---------|------|--------|-------|------|------|------|------|------|------|------|------|------|------|-------|------|------|------|------|------|------|
| TOR- |      | 7      | (IN.4   | 0    | 5,90   | . 10  | 1.6  | 4.4  | 9.0  | 2.4  | 5.8  | 7.9  | 4.1  | 7    | 4.3  | 8.2  | 6.0   | 2.4  | 7.4  | 4.46 | 0000 | 50.0 | 0.0  |
| W    | -    | 77     | (IN.3   | Œ    | 5.64   | 1     | 9.   | 6.   | 2.4  | 3.6  | 4.7  | 5.3  | 7.0  | .3   | 9.6  | 0.5  | 2.2   | 3.8  | 8.2  | 4.8  | 0.0  | 0.0  | 0.0  |
| 90   | S    | IY     | (IN. 4) | -    | 20-22  | 6.4   | 8.5  | 7.1  | 5.1  | 4.9  | 6.9  | 2.9  | 13.0 | 7.6  | 43.9 | 55.3 | 77.77 | 00.2 | 46.5 | 86.3 | 4.0  | 4.0  | 4.0  |
| u    | -    | ×      | -       | 8    | 1.72   | 7     | .7   | .2   | 8    |      | 1.   | 0.   | 1.   | .2   | 80   | .2   | 6.    | 4.   | 3    | 0.   | 0.   | 0    | 0    |
| _    | -    | IXX    | -       | 00   | 1.79   | 4     | 3    | .2   | 4.   | 9.   | 9.   | .3   | 4.0  | 6.   | 3.6  | 4.8  | 7.3   | 9.2  | 6.9  | 5.0  | 0.0  | 0.0  | 0.0  |
| AL   | H    | S      | CIN.    |      | 0.226  | .23   | .23  | .22  | .21  | .20  | .19  | •19  | .18  | .17  | .16  | 116  | .15   | .15  | •16  | 119  | • 00 | .00  | 00.  |
|      | EGNE | WEIGHT | (18.    | 6    | 19.60  | Si    | 5.7  | 5.7  | 7.1  | 0.2  | 7.6  | 7.0  | 8.0  | 7.7  | 9.9  | 4.9  | 4.9   | 7.3  | 8.4  | 8.1  | 4.6  | 7.1  | 4.5  |
|      |      | HOR    | (IN.)   | 5.8  | 17.40  | 8.9   | 0.5  | 2.0  | 3.7  | 5.3  | 6.8  | 8.5  | 0.0  | 1.6  | 3.2  | 4.7  | 4.9   | 7.9  | 6.2  | 6.9  | 6.9  | 6.9  | 6.9  |
|      |      |        | •       | 32.0 | 410.40 | 88.8  | 67.2 | 45.6 | 24.0 | 02.4 | 80.8 | 59.5 | 37.6 | 16.0 | 4.46 | 72.8 | 51.2  | 29.6 | 08.0 | 86.4 | 4.8  | 3.2  | 4.0  |

BEARING FLEXIBILITY 15 MILLION IN.LB. PER RAD.

PRECONE ANGLE 3.59 DEG. AT 0 DEG THIST PRELAG ANGLE -3.66 DEG.

TWIST VARIATIONS +4, 0, -4, -8 DEG.

TABLE 8-56

BASIC BLADE DATA

C2-R COMPOUND

1-2 PLANFORM, RIGID BLADE
GROSS WEIGHT 27,000 LB., 200-KNOT DESIGN

|       |       | EGME  | WALL<br>THICK- | FLAT-<br>WISE | SECTION | EDGE-<br>WISE | SEC-<br>TION | TOR-<br>SION |       |
|-------|-------|-------|----------------|---------------|---------|---------------|--------------|--------------|-------|
| ADI   | I     |       | ESS            | ×             | ×       | IYY           | 7            | 7            | AREA  |
| (IN.) | (IN.) | (18   | Z              |               |         | 2             | (IN.()       | (IN.1)       | ż     |
| 2.0   | 7.0   | 6     | .07            | _             | 5       | 5.1           | 5            | 7.48         | 4.6   |
| 10    | 26.40 | 19.60 | 0.144          | 4.80          | 3.03    | 50.29         | 61.6         | 4.           | 29.36 |
| 8.8   | 5.7   | 4.5   | .16            | 5.08          | .2      | 1.2           | 9.           | 4.           | 7.5   |
| 67.2  | 5.0   | 5.7   | 119            | 5.41          | 9.      | 9.8           | 6.0          | 8.2          | 5.5   |
| 45.6  | 4.4   | 5.7   | .20            | 5.44          | 1       | 9.2           | 1.2          | 8.2          | 1 . 4 |
| 24.0  | 3.6   | 7.1   | .21            |               | . 8     | 4.5           | 2.3          | 8.9          | 2.1   |
| 02.4  | 2.9   | 0.2   | .22            | 5.16          | 1.      | 0.7           | 2.0          | 7.7          | 9.0   |
| 80.8  | 2.3   | 7.6   | .23            | 0             | 9.      | 7.8           | 1.7          | 7.0          | 9.3   |
| 59.2  | 1.6   | 7.0   | .25            | 9.            | .5      | 4.4           | 1.4          | 1.9          | 6-1   |
| 37.6  | 1.0   | 8.0   | .26            |               | .5      | 1.3           | 1.1          | 5.2          | 5.7   |
| 16.0  | 0.3   | 7.7   | .28            | Ò             | .3      | 7.9           | 0.8          | 4.4          | 5.4   |
| 94.4  | 9.6   | 9.9   | .29            | 1             | .2      | 4.6           | 4.           | 3.4          | 4.1   |
| 72.8  | 8.9   | 4.9   | .31            | 3.46          | 0.      | 1.1           | 0.0          | 12.42        | 2.8   |
| 51.2  | 8.2   | 4.9   | .33            | 7             | .8      | 7.8           | .5           | 1.5          | 1.6   |
| 29.6  | 7.5   | 7.3   | .36            | •             | 9.      | 5.1           | 1.           | 0.5          | 0     |
| 08.0  | 7.0   | 8.4   | .43            | 6.            | 6.      | 5.0           | S            | 0.5          | 0.3   |
| 86.4  | 1     | 8.1   | .71            | N             | 9.      | 8.0           | 9.           | 3.9          |       |
| 4.8   | 1     | 4.6   | 00.            | 0.0           | 0       | 0.0           | 0.0          | 0.0          | 00.00 |
| 3.2   | 1     | 7.1   | 00.            | •             | 0       | 0.0           | •            | 0            | •     |
| 4.0   | -     | .5    | 00.            | 0.0           | 0       | 0.0           | 0.0          | 50.0         | 00.00 |

BEARING FLEXIBILITY 15 MILLION IN.LB. PER RAD.

PRELAG ANGLE -4.26 DEG. AT 0 DEG THIST PRECONE ANGLE 3.25 DEG.

TWIST VARIATIONS +4, 0, -4, -8 DEG.

THIST VARIATIONS +2, 0, -2,

TABLE 3-57

BASIC BLADE DATA
C3-R COMPOUND
1-1 PLANFORM, RIGID BLADE
GROSS WEIGHT 14,000 LB., 250-KNOT DESIGN

|        |       |        | AL     | _    | u        | 20    | W    | 0       | 10    |
|--------|-------|--------|--------|------|----------|-------|------|---------|-------|
|        |       | EGME   | THICK- | MISE | TION     | WISE  | TION | NOIS    | LINE  |
| ADI    | HOR   | WEIGHT | ES     | ×    | ×        | 1 1   |      | 7       | RE    |
| CIN.   | (IN.) | (18.   | Z      | -    | -        | Z     |      | (IN. 1) | ż     |
| 36.0   | 8.2   | •      | .07    | 0.   | 0.92     | 0.3   | .5   | 6       | 2.9   |
| 19.2   | 8.2   | 6.     | .14    | 6.   | $\infty$ | 0.5   | 0    | 6.      | 5.9   |
| 02.4   | 8.2   | 8.8    | .14    | 0    | 8        | 0.7   | 1.   | 0       | 2.9   |
| 285.60 | 18.25 | 8.40   | 0.151  | 2.02 | 1.90     | 20.90 | 5.10 | 6.15    | 13.00 |
| 68.8   | 8.2   | .2     | .15    | 0    | 6.       | 1.0   | .2   | .3      | 3.0   |
| 52.0   | 8.2   | .2     | .15    | .1   | 0.       | 3.8   | .5   | •       | 3.1   |
| 35.2   | 8.2   |        | 116    | .2   | 0.       | 4.0   | 9.   | 6.      | 3.1   |
| 18.4   | 8.2   | 4.     | .16    | 63   | 7.       | 4.5   | 1.   | -       | 3.2   |
| 9.10   | 8.2   | .5     | .17    | .3   | .2       | 4.8   | 8    | 4.      | 3.2   |
| 84.8   | 8.2   | .9     | .17    | 4.   | .2       | 7.0   |      | 9.      | 3.3   |
| 68.0   | 8.2   | 6.     | .18    | .5   | .3       | 7.2   | .2   | 6.      | 3.3   |
| 51.2   | 8.2   | 0      | .18    | S    | .3       | 7.8   | .2   | .2      | 3.4   |
| 34.4   | 8.2   | 7.     | .19    | • 6  | 4.       | 8.5   | 4.   | .5      | 3.4   |
| 17.6   | 8.2   | .8     | .19    | 1    | .5       | 9.0   | .5   | -1      | 3.5   |
| 8.00   | 8.2   | 0      | .20    | 8    | 2.60     | 9.5   | 1.   | 0.      | 3.5   |
| 4.0    | 8.2   | .2     | .20    | 6.   | • 6      | 0.0   | .8   | •       | 3.6   |
| 7.2    | 7.    | 4.     | .21    |      | 1.       | 1.2   | 1.   | 4.0     | 3.7   |
| 9.0    | .1    | 2.1    | .27    | 0    | 0.       | 3.0   | 0.   | 0.0     | 4.8   |
| 3.6    | -     | 9.1    | .50    | 0.   | 0.       | 3.0   | 0    | 5.0     | 0.0   |
| 6.8    | -     | 1.8    | .00    | 0    | •        | 3.0   | 0.   | 0       | 0.0   |
| 2.6    | -     | 8      | 00.    | 2.00 | 0        | 3.0   | 00-9 | 000     | 000   |

## BEARING FLEXIBILITY 9 MILLION IN.LB. PER RAD.

TABLE 8-58

BASIC BLADE DATA
C3-R COMPOUND
N.L. PLANFORM, RIGID BLADE
GROSS WEIGHT 14,000 LB., 250-KNOT DESIGN

| MID     | AREA   | ż      | •2   | 5    | 9.   | •    | 13.00 | -    | -    | 2    | .2   | .3   | .3   | 4.   | 4.   | .5   | .5   | 3.6 | 3.7 | 4.8 | 0.0 | 100.00 | 0.0   |
|---------|--------|--------|------|------|------|------|-------|------|------|------|------|------|------|------|------|------|------|-----|-----|-----|-----|--------|-------|
| T08-    | 3      | (IN.A) | 4.   | 6.   | .2   | 6.   | 6.30  | 9.   | 6.   | -    | 4.   | 9.   | 6.   | .2   | 5    | .7   | 0    | •   | 4.0 | 0.0 | 5.0 | 100.00 | 0.0   |
| SECTION | 77     |        | 8    | 1    | 8    | 6.   | .2    | .5   | 9.   | 1.   | .8   | 1.   | .2   | .2   | 4.   | 5    | 1.   | 8   | 1.  | 0.  | 0.  | 6.00   | •     |
| _       | 17     | Z      | 8    | .7   | -    | 3.9  | 1.0   | 3.8  | 4.0  | 4.5  | 4.8  | 7.0  | 7.2  | 7.8  | 8.5  | 9.0  | 9.5  | 0.0 | 1.2 | 3.0 | 3.0 | 23.00  | 3.0   |
| SEC-    | X      | -      | .2   | 4.   | 6.   | 4.   | 6.    | 0    | 0.   |      | .2   | .2   | .3   | 3    | 4.   | .5   | 9.   | 9.  | 1.  | 0.  | 0   | 3.00   | 0.    |
| FLAT-   | IXX    | (IN.7) | 0.12 |      | 9.   | .2   | 0     |      | .2   | .3   | .3   | 4.   | .5   | .5   | 9.   | 1    | 8    | 6.  | 7   | 0   | 0.  |        | 0     |
| WALL    | ESS    | Z      |      | .33  | .23  | .18  | •15   | .15  | •16  | .16  | .17  | .17  | .18  | .18  | .19  | •10  | .20  | .20 | .20 | .27 | .50 | .00    | 0     |
| FCMF    | WEIGHT | (18.   | •    | 6.   |      | 4.   | .2    | .2   | .3   | 4.   | .5   | 6.   | 6.   | 0.   | -    | .8   | 0.   | .2  | 4.  | 2.1 | 9.1 | 1.8    | 14.80 |
|         | HOR    | (IN.)  | 0    | 7.   | 2.1  | 5.5  | .2    | 8.2  | 8.2  | 8.2  | 8.2  | 8.2  | 8.2  | 8.2  | 8.2  | 8.2  | 8.2  | 8.2 | -   | -   | 1.  | 8.10   | -     |
|         | ADI    | ( .N.) | 36.0 | 19.2 | 02.4 | 85.6 | 8.8   | 52.0 | 35.2 | 18.4 | 9.10 | 84.8 | 68.0 | 51.2 | 34.4 | 17.6 | 00.8 | 4.0 | 7.2 | 0.4 | 3.6 | 16.80  | •     |

BEARING FLEXIBILITY 9 MILLION IN-LB. PER RAD.

RECONE ANGLE 0.79 DEG. AT -2 DEG TWIST PRELAG ANGLE -2.37 DEG.

THIST VARIATIONS +2. 0. -2; -4 DEG.

TABLE 8-59

BASIC BLADE DATA

C3-R COMPOUND

3-1 PLANFORM, RIGID BLADE

GROSS WEIGHT 14,000 LB., 250-KNOT DESIGN

| ORD         WEIGHT         THICK-         MISE         TION         MISE         TION         SION           0RD         WEIGHT         NESS         IXX         ZXX         IYY         ZYY         J           N.)         (LB.)         (IN.)         (IN.)         (IN.)         (IN.)         J           .20         2.27         0.100         0.45         0.56         5.13         1.63         2.8           .40         10.99         0.210         0.90         1.12         10.25         3.26         2.8           .40         10.99         0.210         0.90         1.12         10.25         3.26         2.8           .50         8.20         0.180         1.74         1.71         17.98         4.47         5.3           .00         8.21         0.160         2.54         2.19         27.42         5.84         7.8           .00         8.21         0.140         3.69         2.79         37.17         6.99         10.9           .00         8.53         0.140         3.69         2.79         37.17         6.99         10.9           .40         8.53         0.140         4.34         3.12<  |     |      | ALL  |     | THE STATE OF | 90  | EC  | TOR- | 01  |
|--|-----|------|------|-----|--------------|-----|-----|------|-----|
| RD         WEIGHT         NESS         IXX         ZXX         IYY         ZYY         J         AREA           1         (LB.)         (IN.)         (IN.4)   |     | EGNE | HICK | -   | -            | S   |     | 2    | Z   |
| (LB.)         (IN.)         (IN.) <th< th=""><th>K</th><th>EIGH</th><th>ES</th><th>×</th><th>×</th><th>IY</th><th>7</th><th></th><th>RE</th></th<> | K   | EIGH | ES   | ×   | ×            | IY  | 7   |      | RE  |
| 2.20         2.27         0.100         0.45         0.56         5.13         1.63         1.41         3.5           3.40         10.99         0.210         0.90         1.12         10.25         3.26         2.83         7.11           4.60         8.88         0.190         1.15         1.32         12.61         3.69         3.59         8.7           5.80         8.40         0.180         1.42         1.50         15.21         4.10         4.36         10.5           6.80         8.40         0.180         1.74         1.71         17.98         4.47         5.32         12.46         10.5           9.40         8.31         0.160         2.12         1.94         23.46         5.41         6.46         14.4         14.4           9.40         8.51         0.140         3.09         2.49         32.21         6.46         9.28         14.6         9.28         14.6         9.28         14.6         9.28         14.6         9.28         14.6         9.28         14.6         9.28         14.6         9.28         14.6         9.28         14.6         9.28         14.6         9.28         14.6         9.28         14.6  | •   | (18. | Z.   | -   | =            | Z   | Z   |      | ż   |
| 3.40         10.99         0.210         0.90         1.112         10.25         3.26         2.83         7.11           4.60         8.88         0.190         1.15         1.32         12.61         3.69         3.59         8.71           5.80         8.40         0.180         1.74         1.71         17.98         4.47         5.32         12.4           7.00         8.27         0.170         1.74         1.71         17.98         4.47         5.32         12.4           8.20         8.26         0.160         2.12         1.94         23.66         5.41         6.46         14.4           9.40         8.31         0.150         2.54         2.19         27.42         5.44         7.80         16.53           2.00         8.53         0.140         4.94         3.12         45.41         7.98         17.98         24.2           2.00         8.96         0.140         4.94         3.38         51.04         8.52         14.69         26.9           4.40         9.16         0.130         6.53         4.06         65.18         9.99         19.66         32.8           8.00         1.20         8.  | 2.2 | ~    | .10  |     | 3            |     | 9.  | 4.   | 5   |
| 4.60         8.88         0.190         1.15         1.32         12.61         3.69         3.59         8.7           5.80         8.40         0.180         1.42         1.50         15.21         4.10         4.36         10.5           7.00         8.27         0.170         1.74         1.71         17.98         4.47         5.32         12.4           8.20         8.26         0.160         2.12         1.94         23.66         5.41         6.46         14.4         5.32         12.4           9.40         8.31         0.150         2.54         2.19         27.42         5.84         7.80         16.5           9.70         8.53         0.140         4.34         3.12         45.41         7.98         12.98         24.2           4.40         8.97         0.130         4.94         3.38         51.04         8.52         14.69         26.9           5.60         9.04         0.130         4.94         3.38         51.04         8.52         14.69         25.6           8.00         7.85         0.120         4.97         4.97         4.97         4.97         4.97         4.97         4.97         4.97  | 3.4 | 6.0  | .21  |     | 7.           | 0.2 | .2  | 8    | .1  |
| 5.80         8.40         0.180         1.42         1.50         15.21         4.10         4.36         10.5           7.00         8.27         0.170         1.74         1.71         17.98         4.47         5.32         12.4           8.20         8.26         0.160         2.12         1.94         23.66         5.41         6.46         14.4           9.40         8.31         0.150         2.54         2.19         27.42         5.84         7.80         16.5           9.40         8.31         0.140         3.09         2.49         32.21         6.46         9.28         19.0           2.00         8.53         0.140         3.69         2.79         37.17         6.99         10.92         21.7           2.00         8.53         0.140         4.34         3.12         45.41         7.98         12.98         24.2           3.20         8.91         0.130         4.94         3.38         51.04         8.52         14.69         26.9           4.40         8.93         0.130         4.94         3.38         51.04         8.52         14.69         29.8           8.00         0.120         8.7  | 4.6 | 8.8  | .19  |     | .3           | 2.6 | •6  | .5   | 1.  |
| 7.00         8.27         0.170         1.74         1.71         17.98         4.47         5.32         12.4           8.20         8.26         0.160         2.12         1.94         23.66         5.41         6.46         14.4           9.40         8.31         0.150         2.54         2.19         27.42         5.84         7.80         16.5           0.70         8.40         0.140         3.09         2.49         32.21         6.46         9.28         19.0           2.00         8.53         0.140         3.09         2.79         37.17         6.99         10.92         21.7           2.00         8.96         0.140         4.34         3.12         45.41         7.98         12.98         24.2           4.40         8.97         0.130         4.94         3.38         51.04         8.52         14.69         26.9           5.60         9.04         0.130         4.94         3.38         51.04         8.52         14.69         26.9           8.00         7.85         0.120         7.51         4.47         73.16         10.77         22.25         36.0           8.04         8.22         0.  | 5.8 | 4.   | .18  | •   | 3            | 5.2 | ~   | .3   | 0.5 |
| 8.20         8.26         0.160         2.12         1.94         23.66         5.41         6.46         14.46           9.40         8.31         0.150         2.54         2.19         27.42         5.84         7.80         16.5           0.70         8.40         0.140         3.09         2.49         32.21         6.46         9.28         19.0           2.00         8.53         0.140         4.34         3.12         45.41         7.98         10.92         21.7           3.20         8.96         0.140         4.34         3.12         45.41         7.98         12.98         24.2           4.40         8.97         0.130         4.94         3.38         51.04         8.52         14.69         26.9           5.60         9.04         0.130         6.53         4.06         65.18         9.99         19.66         32.8           8.00         7.85         0.120         7.51         4.47         73.16         10.77         22.25         36.0           9.20         8.03         0.120         8.71         4.97         82.90         11.68         25.40         39.2           4.06         8.25 <td< td=""><td>7.0</td><td>.2</td><td>.17</td><td></td><td>1.</td><td>7.9</td><td>4.</td><td>.3</td><td>2.4</td></td<>   | 7.0 | .2   | .17  |     | 1.           | 7.9 | 4.  | .3   | 2.4 |
| 9.408.310.1502.542.1927.425.847.8016.50.708.400.1403.092.4932.216.469.2819.02.008.530.1403.692.7937.176.9910.9221.72.008.530.1404.343.1245.417.9812.9824.24.408.970.1304.943.3851.048.5214.6926.95.609.040.1306.534.0665.189.9919.6632.86.809.160.1306.534.0665.189.9919.6632.88.007.850.1208.714.4773.1610.7722.2536.09.208.030.1208.714.9782.9011.6825.4039.24.007.440.12011.466.04105.8013.7235.3446.14.5012.190.14028.5114.4818.0010.0035.0050.05.0071.842.00030.0015.0018.0010.0035.00100.005.0014.802.00030.0015.0018.0010.00100.00100.00  | 8.2 | .2   | .16  |     | 6.           | 3.6 | 4.  | 4.   | 4.4 |
| 0.708.400.1403.092.4932.216.469.2819.02.008.530.1403.692.7937.176.9910.9221.73.208.960.1404.343.1245.417.9812.9824.24.408.970.1304.943.3851.048.5214.6926.95.609.040.1306.534.0665.189.9919.6632.86.807.850.1207.514.4773.1610.7722.2536.09.208.030.1208.714.9782.9011.6825.4039.29.408.220.1209.965.4692.9012.4929.3342.64.007.440.12011.466.04105.8013.7235.3446.14.5012.190.14028.5114.4818.0010.0035.0050.05.0071.842.00030.0015.0018.0010.0035.00100.005.0014.802.00030.0015.0018.0010.00100.00100.00   | 9.4 | 3    | .15  |     | 1.           | 7.4 | 8   | 8    | 6.5 |
| 2.008.530.1403.692.7937.176.9910.9221.73.208.960.1404.343.1245.417.9812.9824.24.408.970.1304.943.3851.048.5214.6926.95.609.040.1305.683.7057.669.2217.1529.86.809.160.1306.534.0665.189.9919.6632.88.007.850.1208.714.4773.1610.7722.2536.09.208.020.1208.714.9782.9011.6825.4039.26.408.220.1209.965.4692.9012.4929.3342.64.007.440.12011.466.04105.8013.7235.3446.14.5012.190.14028.5114.4818.0010.0035.0050.05.0071.842.00030.0015.0018.0010.0035.00100.05.0014.802.00030.0015.0018.0010.00100.00100.0  | 0.7 | 4.   | 11.  | 0   | 4.           | 2.2 | 4.  | .2   | 9.0 |
| 3.208.960.1404.343.1245.417.9812.9824.24.408.970.1304.943.3851.048.5214.6926.95.609.040.1306.534.0665.189.9919.6632.86.809.160.1306.534.0665.189.9919.6632.88.007.850.1207.514.4773.1610.7722.2536.09.208.030.1208.714.9782.9011.6825.4039.20.408.220.1209.965.4692.9012.4929.3342.64.007.440.12011.466.04105.8013.7235.3446.14.5012.190.14028.5114.4818.0010.0035.0050.05.0049.171.50030.0015.0018.0010.0035.00100.005.0014.802.00030.0015.0018.00100.00100.00100.005.0014.802.00030.0015.0018.00100.00100.00100.00   | 2.0 | .5   | .14  | 9.  | 1.           | 7.1 | 6.  | 0.9  | 1.7 |
| 4.40         8.97         0.130         4.94         3.38         51.04         8.52         14.69         26.9           5.60         9.04         0.130         5.68         3.70         57.66         9.22         17.15         29.8           6.80         9.16         0.130         6.53         4.06         65.18         9.99         19.66         32.8           8.00         7.85         0.120         7.51         4.47         73.16         10.77         22.25         36.0           9.20         8.03         0.120         8.71         4.97         82.90         11.68         25.40         39.2           0.40         8.22         0.120         11.46         6.04         105.80         12.49         29.33         42.6           4.00         7.44         0.120         11.46         6.04         105.80         13.72         35.34         46.1           4.50         12.19         0.140         28.51         14.48         18.00         10.00         55.00         55.00         18.00         10.00         35.00         50.0           5.00         14.80         2.000         30.00         15.00         18.00         10.00 <th< td=""><td>3.2</td><td>6.</td><td>.14</td><td>.3</td><td>7.</td><td>5.4</td><td>6.</td><td>2.9</td><td>4.2</td></th<>   | 3.2 | 6.   | .14  | .3  | 7.           | 5.4 | 6.  | 2.9  | 4.2 |
| 5.609.040.1305.683.7057.669.2217.1529.86.809.160.1306.534.0665.189.9919.6632.88.007.850.1207.514.4773.1610.7722.2536.09.208.030.1208.714.9782.9011.6825.4039.20.408.220.1209.965.4692.9012.4929.3342.64.007.440.12011.466.04105.8013.7235.3446.14.5012.190.14028.5114.4818.0010.0035.3050.05.0071.842.00030.0015.0018.0010.0035.00100.005.0014.802.00030.0015.0018.0010.00100.00100.00   | 4.4 | 6.   | .13  | 6.  | .3           | 1.0 | 5   | 4.6  | 6.9 |
| 6.80       9.16       0.130       6.53       4.06       65.18       9.99       19.66       32.8         8.00       7.85       0.120       7.51       4.47       73.16       10.77       22.25       36.0         9.20       8.03       0.120       8.71       4.97       82.90       11.68       25.40       39.2         0.40       8.22       0.120       9.96       5.46       92.90       12.49       29.33       42.6         4.00       7.44       0.120       11.46       6.04       105.80       13.72       35.34       46.1         4.50       12.19       0.140       28.51       14.48       18.00       10.00       65.76       49.1         5.00       49.17       1.500       30.00       15.00       18.00       10.00       35.00       50.0         5.00       71.84       2.000       30.00       15.00       18.00       10.00       100.00       100.00         5.00       14.80       2.000       30.00       15.00       18.00       10.00       100.00       100.00         5.00       14.80       2.000       30.00       15.00       18.00       10.00       100.00       1  | 5.6 | 0    | .13  | 9.  | 1.           | 7.6 | .2  | 7.1  | 8.6 |
| 8.00         7.85         0.120         7.51         4.47         73.16         10.77         22.25         36.0           9.20         8.03         0.120         8.71         4.97         82.90         11.68         25.40         39.2           0.40         8.22         0.120         9.96         5.46         92.90         12.49         29.33         42.6           4.00         7.44         0.120         11.46         6.04         105.80         13.72         35.34         46.1           4.50         12.19         0.140         28.51         14.48         18.00         10.00         65.76         49.1           5.00         69.17         1.500         30.00         15.00         18.00         10.00         35.00         50.0           5.00         71.84         2.000         30.00         15.00         18.00         10.00         100.00         100.00           5.00         14.80         2.000         30.00         15.00         18.00         10.00         100.00         100.00           5.00         14.80         2.000         30.00         15.00         18.00         10.00         100.00         100.00   | 6.8 | 7.   | .13  | .5  | 0.           | 5.1 | 6.  | 9.6  | 2.8 |
| 9.208.030.1208.714.9782.9011.6825.4039.20.408.220.1209.965.4692.9012.4929.3342.64.007.440.12011.466.04105.8013.7235.3446.14.5012.190.14028.5114.4818.0010.0065.7649.15.0069.171.50030.0015.0018.0010.0035.0050.05.0071.842.00030.0015.0018.00100.00100.005.0014.802.00030.0015.0018.0010.00100.00  | 8.0 | 8    | .12  | .5  | 4.           | 3.1 | 0.7 | 2.2  | 0.9 |
| 0.40       8.22       0.120       9.96       5.46       92.90       12.49       29.33       42.6         4.00       7.44       0.120       11.46       6.04       105.80       13.72       35.34       46.1         4.50       12.19       0.140       28.51       14.48       18.00       10.00       65.76       49.1         5.00       69.17       1.500       30.00       15.00       18.00       10.00       35.00       50.0         5.00       71.84       2.000       30.00       15.00       18.00       10.00       100.00       100.0         5.00       14.80       2.000       30.00       15.00       18.00       10.00       100.00       100.0  | 9.2 | 0    | .12  | .7  | 6.           | 2.9 | 1.6 | 5.4  | 9.5 |
| 4.00       7.44       0.120       11.46       6.04       105.80       13.72       35.34       46.1         4.50       12.19       0.140       28.51       14.48       18.00       10.00       65.76       49.1         5.00       69.17       1.500       30.00       15.00       18.00       10.00       35.00       50.0         5.00       71.84       2.000       30.00       15.00       18.00       10.00       100.00       100.0         5.00       14.80       2.000       30.00       15.00       18.00       10.00       100.00       100.00  | 4.0 | .2   | .12  | 6.  | 4.           | 2.9 | 2.4 | 9.3  | 2.6 |
| 4.5012.190.14028.5114.4818.0010.0065.7649.15.0069.171.50030.0015.0018.0010.0035.0050.05.0071.842.00030.0015.0018.0010.00100.005.0014.802.00030.0015.0018.0010.00100.00   | 4.0 | 4.   | .12  | 1.4 | 0.           | 5.8 | 3.7 | 5.3  | 6.1 |
| 5.00 69.17 1.500 30.00 15.00 18.00 10.00 35.00 50.0<br>5.00 71.84 2.000 30.00 15.00 18.00 10.00 100.00 100.0<br>5.00 14.80 2.000 30.00 15.00 18.00 10.00 100.00  | 4.5 | 2.1  | .14  | 8.5 | 4.4          | 8.0 | 0.0 | 5.7  | 9.1 |
| 5.00 71.84 2.000 30.00 15.00 18.00 10.00 100.00 100.0 5.00 14.80 2.000 30.00 15.00 18.00 10.00 100.00 100.0  | 5.0 | 9.1  | .50  | 0.0 | 5.0          | 8.0 | 0.0 | 5.0  | 0.0 |
| 5.00 14.80 2.000 30.00 15.00 18.00 10.00 100.00 100.0  | 5.0 | 1.8  | 00.  | 0.0 | 5.0          | 8.0 | 0.0 | 00.0 | 0.0 |
|  | 5.0 | 4.8  | .00  | 0.0 | 5.0          | 8.0 | 0.0 | 00.0 | 0.0 |

BEARING FLEXIBILITY 10 MILLION IN.LB. PER RAD.

PRECONE ANGLE 1.00 DEG. AT -2 DEG TWIST PRELAG ANGLE -2.80 DEG.

THIST VARIATIONS +2, 0, -2, -4 DEG.

TABLE 8-60

BASIC BLADE DATA
C3-R COMPOUND
1-2 PLANFORM, RIGID BLADE
GROSS WEIGHT 14,000 LB., 250-KNOT DESIGN

| TOR- MID-<br>SION LINE<br>J AREA<br>(IN.4) (IN.2) | 9.5   | 43 18.               | .62 14.7<br>.43 13.6 | .19 12.7<br>.87 11.7 | 7 10.6<br>2 9.8 | -0.5 | 26 6.8 |      |
|---|-------|----------------------|----------------------|----------------------|-----------------|------|--------|------|
| SEC-<br>TION<br>ZYY<br>(IN-37)                    | 2.73  | 4 40                 | 4 7                  | 20                   | 700             | 4.83 | 5.2    | -    |
| EDGE-<br>HISE<br>IYY<br>(IN.4)                    | 13.29 | 25.48                | NE                   | 7-1                  | 2.0             | 000  | 75     | 9.   |
| SEC-<br>TION<br>ZXX<br>(IN-3)                     | 1.05  | 000                  | 1.94                 | 1.95                 | 1.80            | 1.69 | 1.57   | 1.38 |
| FLAT-<br>WISE<br>IXX<br>(IN.4)                    | • •   | 2.50                 | 70                   | 0.00                 |                 | 4 6  |        | 0 4  |
| WALL<br>THICK-<br>NESS<br>(IN.)                   | 0.1   | 0.134                | •16                  | 118                  | 22              | .24  | .30    | 33   |
| SEGMENT<br>WEIGHT<br>(LB.)                        | 100   | 8.40<br>8.40<br>8.27 | . u.                 | 4 10 0               | 20              | - 8  | 0 7    | 4 -  |
| CHORD (IN.)                                       | 700   | 19.50                | 8.7                  | 5.1                  | 5.6             | 4-6  | 13.60  | - 4  |
| ADII  | 96.0  | U EN ED              | 2.5                  |                      | 8.0             | 4.4  |        | 14   |

BEARING FLEXIBILITY 12 MILLION IN.LB. PER RAD.

PRECONE ANGLE 0.67 DEG. AT -2 DEC THIST PRELAG ANGLE -3.53 DEG.

TWIST VARIATIONS +2, 0, -2, -4 DEG.

PRELAG ANGLE -1.80 DE PRECONE ANGLE 0.80 DEG. AT -2 DEG DESIGN THIST

THIST VARIATIONS +2, 0, -2, -4 DEG.

TABLE 8-61

BASIC BLADE DATA C4-R COMPOUND 1-1 PLANFORM, RIGID BLADE GROSS WEIGHT 30,000 LB., 250-KNOT DESIGN

| MID-<br>LINE<br>AREA<br>(IN.2)  | 42.70 | 42.80  | 0            | 3.0   | 24   | 3.4  | 3.1    |      | 2            | 50.50 | 0    | 0.0 | 150-00 |
|---------------------------------|-------|--------|--------------|-------|------|------|--------|------|--------------|-------|------|-----|--------|
| SION<br>JA                      | 25.00 | -5     |              | 6.    | 80   | 5    | 70.00  | - 4  | 20.          | •     | 00   | 90  | 00     |
| SEC-<br>TION<br>ZYY<br>(IN. 3)  | 11.50 | 23.30  | 5.0          | 6 5   | 91   | ::   | 9.0    | *    | 9.3          | 8.5   | 00   | 000 | 0.0    |
| EDGE-<br>WISE<br>IYY<br>(IN.4)  | 88.50 | 0.0    | 93.          | 95.   | 050  | 13.  | 225.00 | 70.  | 14.0         | 98.0  | 32.0 | 32. | 2.0    |
| SEC-<br>TION<br>ZXX<br>(IN.3)   | 4.50  | - 4    | 9.80         | 10.00 | 4.0  |      | 11.50  | u    | 16.80        | 30.50 | 0.0  | 0.0 | 40.00  |
| FLAT-<br>WISE<br>IXX<br>(IN.4)  | 8.50  |        | 18.00        | 8     | 6    |      | 22.00  | 8.   | - 4          | 4     | 07.  | 1.  | 07.0   |
| WALL<br>THICK-<br>NESS<br>(IN.) | 10.   | 0.220  | .23          | .24   | .25  | .26  | .30    | .33  | .39          | .50   | • 00 | 00. | 00.    |
| SEGMENT<br>WEIGHT<br>(LB.)      | 8.8   | 23.52  | 4.7          | 5.7   | 6.0  | 6.0  | 8.3    | 9.7  | 5.9          | 9.0   | 13.7 | .5  | 2.5    |
| CHORD (IN.)                     | \$ 5  | 36.00  | \$ 5         | 9     | , o  | • •  | 9      | 9    | 9            | 4     | 3    | 4   | *      |
| RADII<br>(IN.)                  | 20.0  | 378.00 | 36.0<br>15.0 | 94.0  | 52.0 | 31.0 | 69.0   | 47.0 | 26.0<br>05.0 | 84.0  | 3.0  | 2.0 | 0.0    |

### CANTILEVERED ROOT RESTRAINT

TABLE 8-62

BASIC BLADE DATA
C4-R COMPOUND
N.L. PLANFORM, RIGID BLADE
GROSS WEIGHT 30,000 LB., 250-KNOT DESIGN

| MID-<br>LINE<br>AREA<br>(IN.2)  | 5.24 10.49 21.74        | 6.2<br>2.9<br>3.0    | .2         | 4229                             | 0000                                | 150.00 |
|---------------------------------|-------------------------|----------------------|------------|----------------------------------|-------------------------------------|--------|
| TOR-<br>SION<br>J               |                         | 8.00                 |            | 59.00<br>62.50<br>70.00<br>78.00 | 95.00<br>120.00<br>250.00<br>300.00 | 300.00 |
| SEC-<br>TION<br>ZYY<br>(IN.F)   | 400                     | 4.3                  | 6.0        | 0,000                            | 39.                                 | 100.00 |
| EDGE-<br>WISE<br>IYY<br>(IN.4)  | 17.80<br>35.61<br>73.54 | 24.2<br>88.0<br>93.0 | 95.        | 13.<br>25.                       | 0000                                | 3      |
| SEC-<br>TION<br>ZXX<br>(IN. 3)  | 1.27 2.54 4.52          | 4100                 | 074        | 10.50<br>10.80<br>11.50<br>12.80 | 000                                 | 40.00  |
| FLAT-<br>WISE<br>IXX<br>(IN.4)  |                         | 8.8                  | 866        |                                  |                                     | 07.    |
| WALL<br>THICK-<br>NESS<br>(IN.) | .23<br>.47              | .27<br>.23<br>.23    | .24        | .26                              | 0.390                               | 88     |
| SEGMENT<br>WEIGHT<br>(LB.)      | 8.8<br>0.1              | 3.7                  | 5.0<br>6.0 | 0 - 4 4 -                        | 10001                               | 137.50 |
| CHORD<br>(IN.)                  | 2.0                     | 0.0                  | 0.00       | 0000                             | 0044                                | 14.80  |
| RADII (IN.)                     | 20.<br>99.<br>78.       | 57.<br>36.<br>15.    | 73.        |                                  | 63.                                 | 30.00  |

CANTILEVERED ROOT RESTRAINT

PRELAG ANGLE -1.31 DEG. AT -2 DEG THIST PRECONE ANGLE 0.80 DEG.

THIST VARIATIONS +2, 0, -2, -4 DEG.

PRECONE ANGLE 0.93 DEG. AT -2 DEG TWIST PRELAG ANGLE -1.60 DEG. THIST VARIATIONS +2, 0, -2, -4 DEG.

TABLE 8-63

| BASIC BLADE DATA | C4-R COMPOUND | 3-1 PLANFORM, RIGID BLADE | GROSS WEIGHT 30,000 LB., 250-KNOT DESIGN |
|------------------|---------------|---------------------------|--|
|                  |               |                           | GROS                                     |

|        |       |           | WALL   | FLAT- | w                         | EDGE-   | SEC-    | TOR-    |        |
|--------|-------|-----------|--------|-------|---------------------------|---------|---------|---------|--------|
|        |       | EGM       | THICK- | WISE  | TION                      | WISE    | TION    | SION    | LINE   |
| ADI    | CHORD | WEIGHT    | w      | IXX   | ×                         | >       | 7       | 7       | $\sim$ |
| CIN.   | (IN.) | <b>LB</b> | Z      | (IN.  |                           | (IN. 1) | (IN. 5) | (IN. 4) | _      |
| 20.0   | 4.0   | œ         | .15    | •     | 5                         | 5       | •       | 2.5     | 7.2    |
| 0.66   | 4.9   | 0.1       | .30    |       | -                         | 0       | 5       | 5.0     | 7.2    |
| 378.00 | 8     | 23.52     | 0.280  | 0.3   | 5.97                      | 1111.10 | 17.33   | 30.85   | 33.15  |
| 57.0   | 1.4   | 3.7       | .26    | •     | 9                         | 7.      | 9.      | 8.5     | 0.1    |
| 36.0   | 3.6   | 4.7       | .25    | 5.3   | 9                         | 62.     | 1.      | 5.1     | 6.5    |
| 15.0   | 6.0   | 4.7       | .23    | 8.3   | 3                         | 93.     | 4.      | 4.5     | 3.9    |
| 94.0   | 8.4   | 5.7       | .22    | 1.7   | 4                         | 24.     | 9       | 3.2     | 1.9    |
| 73.0   | 0.8   | 6.0       | .21    | 5.1   | 2                         | .09     | 8.      | 4.6     | 0.3    |
| 52.0   | 3.2   | 6.0       | .21    | 9.2   | 2                         | 01.     | -       | 5.1     | 9.3    |
| 31.0   | 5.6   | 6.6       | .20    | 3.6   | 7                         | 42.     | 3.      | 7.1     | 8.8    |
| 10.0   | 8.0   | 6.7       | •19    | 8.2   | 7                         | 89.     | 9       | 11.2    | 8.8    |
| 89.0   | 9.0   | 8.3       | .19    | 4.9   | 3                         | .09     | 1.      | 33.8    | 9.5    |
| 68.0   | 2.8   | 7.5       | .20    | 9.0   | 9                         | 58.     | 7.      | 68.9    | 19.8   |
| 47.0   | 5.2   | 9.7       | .21    | 3.1   | 0                         | 70.     | 5.      | 6.70    | 1.0    |
| 6.0    | 7.6   | 1.0       | 2      | 0.7   | 2                         | 95.     | 2.      | 52.3    | 42.7   |
| 5.0    | 0.0   | 5.9       | .23    | 10.9  | $\boldsymbol{\mathbf{x}}$ | 33.     | 0       | 6.00    | 54.9   |
| 4.0    | 4.7   | 9.0       | .27    | 21.2  | -                         | 61.     | 5.      | 33.3    | 63.6   |
| 3.0    | 4.7   | 3.7       | 00.    | 80.0  | 0                         | 30.     | 0       | 000     | 0000   |
| 2.0    | 4.7   | 7.5       | 00.    | 80.0  | 0                         | 30.     | 0       | 0.00    | 50.0   |
| 0.0    | 24.74 | .5        | 00.    | 0.0   | 0                         | 30.     | 0       | 0.0     | 50.0   |

#### CANTILEVERED ROOT RESTRAINT

TABLE 8-64

BASIC BLADE DATA C4-R COMPOUND 1-2 PLANFORM, RIGID BLADE GROSS WEIGHT 30,000 LB., 250-KNOT DESIGN

|        |        |         | WALL   | FLAT-  | SEC-         |        |          | TOR-   | -01W   |
|--------|--------|---------|--------|--------|--------------|--------|----------|--------|--------|
|        |        | SEGMENT | THICK- | WI SE  | T 10N        |        |          | NOIS   | LINE   |
| RADII  | CHORD  | WEIGHT  | NESS   | , xxI  | 7 X X Z      |        |          | 7      | AREA   |
|        | ( IN.) | (18.)   | N      | (IN.4) | (IN.)        | (IN.   | ( IN. () | (IN.4) | N.NI   |
| •      | 41.00  | ω.      | •      | •      | •            | 11.    | 2        | 31.50  | 68.31  |
|        | 0      | 0.1     |        | -      | •            | 22.    | \$       | 63.00  | 68.31  |
| 378.00 | 39.10  | 23.52   | 0.202  | 20.79  | 8.86         | 214.40 | 24.57    | 60.31  | 64.65  |
|        | æ      | 3.7     | •      | •      | •            | 07.    | \$       | 58.76  | 61.13  |
|        | -      | 4.7     | •      | 6      | •            | 00     | 4        | 56.03  | 57.68  |
|        | ဖ      | 4.7     | •      | 8      | •            | 94.    | \$       | 54.83  | 54.24  |
|        | 3      | 5.7     | •      | 7      | •            | 83.    | 3.       | 51.40  | 50.35  |
|        | C      | 6.0     | •      | •      | •            | 75.    | 3        | 49.97  | 47.19  |
|        | ~      | 6.0     | •      | 5      | •            | 68.    | 3.       | 47.16  | 44.04  |
|        | -      | 6.6     | •      | 5      | •            | 60.    | 2.       | 44.17  | 41.08  |
| •      | 0      | 6.7     | •      | ;      | •            | 52.    | 2.       | 42.71  | 38.15  |
|        | σ      | 8.3     | •      | 13.88  | •            | 48.    | 2.       | 42.15  | 34.52  |
|        | æ      | 7.5     | •      | *      | •            | 49.    | 3.       | 44.05  | 31.39  |
| •      |        | 9.7     | •      | 14.26  | •            | 47.    | 4        | •      | 28.10  |
|        | o      | 1.0     | •      | \$     | •            | 44.    | 46.4     | 44.33  | 25.16  |
| •      | S      | 5.9     | •      | 13.68  | •            | 39.    | 4.91     | 43.28  | 22.31  |
| •      | 0      | 9.0     | •      | 6      | 3.           | 36.    | 4.80     | 62.85  | 15.50  |
| 3.     | 0      | 3.7     | •      | 0      | 8            | 7.     | 2.00     | 300.00 | 100.00 |
| 2.     | 10.60  | 7.5     | •      | •      | •            | 57.00  | 2.00     | 300.00 | 150.00 |
| •      | 10.60  | 2.5     | •      | ċ      | <b>&amp;</b> |        | 2.00     | 300.00 | 150.00 |

## BEARING FLEXIBILITY 20 MILLION IN. LB. PER RAD.

PRELAG ANGLE -1.87 DEG. PRECONE ANGLE 0.70 DEG. AT -2 DEG TWIST

TWIST VARIATIONS +2, 0, -2, -4 DEG.

#### REFERENCES

- 1. Gerstenberger, W., and Wood, E. R., Analysis of Helicopter Aeroelastic Characteristics in High Speed Flight, I. A. S. Paper No. 63-72 January 1963.
- 2. Wood, E. R., and Hilzinger, K. D., "A Method for Determining the Fully Coupled Aeroelastic Response of Helicopter Rotor Blades", Proceedings of the A. H. S., May 1963.
- High Performance Single Rotor Helicopter Study, T R E C Technical Report 61-44, Contract DA #44-177-TC-648, April 1961.
- 4. Horvay, G., "Stress Analysis of Rotor Blades", Journal of the Aeronautical Sciences, Vol. 14, No. 6, June 1947.
- 5. Wood, E. R., Hilzinger, K. D., and Buffalano, A. C., "An Aeroelastic Study of Helicopter Rotor Systems in High Speed Flight", Proceedings, CAL/TRECOM Symposium, June 1963.
- 6. Critos, C., Heyson, H., and Boswinkle, R., Jr. Aerodynamic Characteristics of N. A. C. A. 0012

  Airfoil Section at Angles of Attack from 0° to 180°, N. A. C. A. TN 3361, 1955.
- 7. Information and Preliminary Data on Helicopter Rotor Blade Dynamic Airloads and Moments as Measured in Flight, U. S. Army TRECOM by N. A. S. A., May 24, 1961.

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